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INAUGURAL ADDRESS

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Everyone who is called to preside over this great Institution must feel, as I do, how high is the honour and how wide the task before him. We have, as an Institution, the responsibility of holding up a mirror to the age by our papers and discussions on all applications of electricity, of guiding education in electrical matters, of framing rules by which electrical work must properly be carried out, and of administering a Benevolent Fund of no mean order. In everything that concerns the welfare of the Institution you may be assured that I shall do all I can during my year of office.

INTRODUCTION.

The profession of engineering, as a branch of applied science, has for its purpose to relieve the race of men from endless toil and discomfort. It is by its nature as much an art as a science; in part a knowledge of principles, and partly the trained skill of their application, and these cannot be entirely divorced. Most of the members of this Institution are engaged in carrying into practice the great laws of electricity in motion. Some are trying according to their vision and opportunity to improve the paths by which electrical science advances; and to a few great ones, whose portraits adorn these walls, it has been given to discover new avenues of advance, to formulate new laws, and, directly or indirectly, to influence for all time the life of man in every corner of the globe. It has been well said by an old philosopher that the future comes from behind over our heads, and even now in study, research room, laboratory, and workshop, new ideas are taking shape by which the course of engineering practice will undoubtedly be changed. There is much in the advanced electrical science of to-day that can never come into practice, but in the maze of experimental research and wave mechanics that is modern physics there is hidden the explanation of some of the outstanding problems of electrical engineering. What, for instance, is the nature of insulation and upon what does the right use of dielectric material depend? Those who had the pleasure of being present at the opening of the Callender Research Laboratories will remember the following remarkable introduction to the description of the works:—

"It is probably true that in no other engineering field does the designer receive so little instruction and guidance from the application of established general principles and basic theory as in the practice of electrical insulation. Industry is impatient, and has to progress without waiting for the slow formulation of fundamental theory. As a result, the insulation engineer has in the past found himself responsible for vast expenditures, with little but empirically gained experience for his guidance. The insulation engineer has generally not only no very definite theoretical guidance as to what kind of failure will occur, but he has also found that empirical tests provide him with no well-defined boundary, beyond which breakdown will arise. Failure is not a function solely of the stresses introduced, but is a function also of the time over which the forces are applied. The insulation engineer has found in the past that the safe working stress in any particular case can only be determined by a patient series of observations over a long period of time.

"In these circumstances it is not surprising to find that in many respects it is the problem of electrical insulation that is holding back the fullest development of high-voltage engineering for the transmission of large blocks of electrical power. These difficulties have almost prohibited the use of cables on the very highest-voltage transmission systems and have rendered commercially unavoidable the use of overhead lines in positions and circumstances for which they are not entirely suitable."

So far as engineers are concerned this urgent problem, so cogently stated, begins with the molecule. Debye's dipole theory of molecular polarization is the most interesting and, on the whole, the most promising of the modern theories of dielectric behaviour, but I venture to

think that the final solution of the problem of electric strength will be found by an application of the methods of wave mechanics to an analysis of the internal and external electrical fields of molecules, as revealed by X-ray and cathode-ray spectrography, and possibly by a new method that I shall describe later. There seems to be behind the behaviour of insulators and the splendid empiricism of cable makers a "hidden simplicity," as Henri Poincaré called it, at least as simple as the free-electron theory of conductors, though much more difficult to reach. There is at the present time no theory of dielectric behaviour that covers all the facts.

I resist the temptation to deal with education, or high-voltage measurements, or the safe use of electricity in coal mines, all of which offer problems, only partially solved, of deep and immediate interest; and I propose to deal very generally with a small part of the great subject of electrical insulation, for recent research has shown that there is an unexpected unity in some of its phenomena. It would be impossible here to review all the work that has been done and the theories that have been advanced even within the last ten years. The excellent surveys of dielectrics issued by the Electrical Research Association cover much of the ground before that, and there is no better reference for recent work than *Science Abstracts* and the special reports that are published from time to time in the *Journal*. I therefore propose to deal only with those researches on insulation of which I have personal knowledge, and to address myself chiefly to the younger members of the Institution, whose duty it will be to carry on the work. For this reason I shall aim at indicating new lines of research rather than at giving an exhaustive survey of the present position.

Surface Insulation.

The most perfect insulator is the ether of space. The cosmic dust that exists there is so tenuous that, no matter how highly charged two stars might be, no lightning flash could pass between them. Gases with molecules a few millionths of a centimetre of ether apart are still good insulators. Some liquids with even closer packing are better still, and certain solids with every degree of density from india-rubber to the diamond are the best of all material substances. But there is a fourth insulating state, distinct from any of these, neither liquid nor gaseous, about which no book has yet been written and on which very little is known, yet which dominates more than any other factor the insulation technique of present high-tension practice. It is that of the moisture films that exist unseen on the surfaces of all solids exposed to the atmosphere. Why is it that such long porcelain or bakelized-paper insulators are found to be necessary for high-tension apparatus when the electric strength of air is 30 000 volts per centimetre? On the grid system, insulators are specified that have a total length of surface approaching 3 metres. Each single suspension element of a chain carries, on test in air, surge potentials approaching 250 kilovolts before flashing over, and its air clearances should carry more, yet nine or ten such insulators are used for a line that has only 78 kilovolts to earth. If one of these insulators is reversed, and tested on surge potential in air, the discharge is seen to go not straight across but to follow every undulation of the surface, as if it were guided. This is due partly to the high dielectric constant of porcelain but also to the moisture on the surface acting as a conductor of electric fields.

The resistivity (ρ) of surface insulation is, for our purpose, defined as the resistance at a given temperature and hygrometric state between the opposite sides of a centimetre square that are at right angles to the field along the surface. From this definition the surface resistance of an area of length l and breadth b is $\rho l/b$, and is therefore independent of the *size* of the surface, depending only upon its proportions. The surface resistance of a kilometre square would be the same as that of a centimetre square, since both sides increase in the same ratio. When the film consists of moisture deposited from the atmosphere its resistivity has values from about 10 megohms at dew point to a "billohm" (10^{12} ohms) or even a "trillohm" (10^{18} ohms). These high values can be measured by an electrometer method; they cannot be directly measured by a galvanometer; the currents at low voltages are usually too small, and, when a high voltage is applied, corona may destroy the film. Our observations prove that the moisture is held on the surface by molecular attraction of the kind known as adsorption. When dew point is approached it may form a continuous film, but when the surface is nearly dry it is discontinuous and at most a few molecules thick, entangled in the molecular pits of which even glazed surfaces consist. On some surfaces that are insoluble in water the films are pure moisture, or as pure as it can be when in contact with air, but on the glazed surfaces of porcelain the films have a dual nature, one part having the characteristics of pure water, the other of a partial or saturated solution of the glaze. If dust deposits on the surface it also enters into semi-solution; and dry dust alone, as we have found, if it has a dielectric constant differing from that of the material of the surface, can greatly modify the surface gradients. If it is more soluble than the glaze it forms a dangerous type of film, which can only be avoided by a design that prevents its continuous deposit on the under-surface of an insulator. Such a design was worked out by Dr. W. G. Thompson as a result of our experience with surface films, and it offers many advantages. The most remarkable feature of these adsorbed films is the manner in which they change when the physical conditions are varied. Most of the changes follow very closely the logarithmic law characteristic of adsorption. Some of the results at low voltages have been described before,* for instance the remarkable changes of resistivity at dew point and with air pressure. A research now in progress on the behaviour of these films in high-voltage alternating fields adds a further link to our knowledge.† Their change with time in a field of constant value is also logarithmic, but with the special feature that when the hygrometric state of the air is above a certain value the application of an electric field dries the film off, and that below this value moisture is attracted by the field and is deposited from the air. I have shown recently in the *Journal* ‡ the striking manner in which invisible moisture on a glazed surface can deflect an electric

* See Reference (1). † *Ibid.*, (2). ‡ *Ibid.*, (3).

field even when the surface resistivity is over 100 megohms per cm^2, and this, when it is able to alter the distribution of the field, no doubt plays a part in the flash-over of line insulators,* but it may also play a part in the arcing-over that sometimes occurs in air-break switches or in switch cubicles. This is usually thought to be due to ionization of the air space or to high-frequency oscillations. Insulating barriers have in certain cases only made matters worse, and it is possible that the reason for this is the manner in which the electrostatic fields that determine flash-over are led by moisture films over the surface of the switch chamber and exposed insulation. The remedy is to paint the insulating parts of the case or cubicle with hard bitumen compound or a similar non-hygroscopic covering. There has been some discussion recently† as to whether in a steam condenser the condensed moisture deposits on the tubes as a film or as drops. The answer to this can be given from these electrical tests. It begins as a film, for there is always such a film on solids in contact with moist air, but in a condenser this film is in a continual state of rapid instability, thickening to a point where drops form suddenly, as shown by Smail, and shrinking again to an invisible layer as they fall off.

The nature and properties of these surface films as they are met with in high-tension measurement and on transmission systems, or in postal telegraph practice, might well repay further research. So far as they affect maintenance and continuity of working they are a strong argument for underground cable systems from which moisture is excluded, and it is possible that the next generation may see the grid system in this country placed underground, not so much to guard it against deliberate or accidental damage by aircraft, as to protect it from the English climate.

Consider for a moment the mechanism by which the different kinds of matter allow an electric current to pass. In metals there is a stream of free electrons slipping from molecule to molecule under the drag of the field. Solid dielectrics conduct by a slow and much hampered transfer of charge from molecule to molecule in a manner resembling that of electrolysis. Insulating liquids conduct in a similar electrolytic manner by a movement of ions in which there is no change of type from the best to the worst insulators. In gases conduction may be either by ions of molecular dimensions —frequently by charged aggregates of molecules—or by free electrons. What Maxwell called a "displacement current" in dielectrics in alternating fields is observed by the terminal effect in the external circuit of changing states of elastic strain in the medium. This strain is most likely one of twist or torsional shear which results in the withdrawal of the free negative electrons on the positive terminal plate into the circuit and, in effect, an equal extrusion of those on the negative plate, the current of the free electrons in the supply circuit being of the normal metallic type. The exact manner of conduction of current across a surface on which there are adsorbed films is not yet known. It may be by actual movement of particles or molecules of water, each moving irregularly as if over a very uneven road but the stream having on the whole a steady direct or alternating rate of flow. Such a mode of transfer is a form of electrical endosmose or, if the particles have acquired an electric charge, of cataphoresis. The electric state of particles of a moisture film in which evaporation or condensation is taking place is not constant and both the above effects may play a part in the passage of current by surface films. The subject is an almost unworked field of great theoretical and practical interest; but from the results I have quoted we see that the formation of moisture films on insulators follows very exact laws, that are only now being discovered. So long as there is overhead transmission its continuity of supply will depend, when the humidity is high, more upon surface moisture than upon any other factor. It is not too much to say that if a robust, insulating, weather-resisting, covering material should ever be discovered on which moisture films could not form or be maintained, so that surface flash-over could not occur, high-tension insulator design would be entirely changed. Meanwhile the world cost of guarding against flash-over, and of maintaining the insulation of overhead lines, must be reckoned in millions of pounds a year.

* See Reference (4). † *Ibid.*, (5).

Gases.

In the absence of specific sources of electrification, such as X-rays or light, all gases are insulators, though of widely different electric strengths. Whilst we are chiefly concerned with air as an insulator, it is only by a study of other gases that we are able to discover the mechanism by which air breaks down. I wish to direct your attention to a recent series of papers on electrical discharge in gases by Dr. J. D. Stephenson from my laboratory, in which new facts are given that are, I believe, of the first importance.* These may be summarized as follows: (1) A gas breaks down when the number of negative ions between the electrodes reaches a certain value that is the same for all gases. (Spark discharge has been shown to consist of a thin luminous line of carriers, thrusting out from the negative pole until it reaches the positive and then thickening as a semi-arc is struck.)† (2) The gradient at which breakdown occurs is the same for corona discharge as for sparks between parallel plates. This shows that the two forms—corona and spark discharge—are essentially one, differing only in their manner of causation. In support of this it has been shown recently that a gas engine will run quite well when the ignition sparks just fail to pass, though a corona glow appears. If this sparkless ignition were confirmed and made practical it might mean a revolution in methods of ignition, and it would dismiss finally the hot-spark theory of ignition.

Stephenson found also that high-voltage spark discharge between parallel plates at voltages of 100 to 200 kV could be repeated many times with a voltage difference of no more than 1 in 1 000 between successive sparks; that the electric strength of air is in fact a physical constant comparable in accuracy of determination with most of the constants of nature. Perhaps the most interesting consequence of these results is the manner in which the electric strength of a gas is found to depend on the structure of its molecules. On the

* See Reference (6). † *Ibid.*, (7).

electrical theory of matter the chemical bonds between atoms forming a molecule are the mechanical forces due to electrical attraction, i.e. to the internal electric fields. These bonds, though exceedingly strong, are elastic, and an electric wave motion such as that of electrons passing across a molecule can set the charges of its atoms in vibration so that it absorbs energy from the wave and may be ionized. The conditions for this have been worked out for monatomic gases and found to agree well with observation, but with anything more complex than that, even a hydrogen or nitrogen molecule, the mathematical theory is not yet entirely competent to deal. An isolated electron passing a molecule is an unsymmetrical or out-of-balance effect, and the theoretical conditions assumed in the wave-mechanics theory do not fully apply.

What happens when an electron driven by an electric field collides with a heavy molecule is a very complex matter about which, as yet, little is known. Molecules have all kinds of shapes; a few of them are in effect spherical, some (like benzene) are flat rings, others (like methane) are tetrahedral, others again (the paraffins for example) are like sausages or flexible chains. Because of these differently shaped targets, each having a characteristic electric field by which an electron is deflected, the form of a molecule might well be thought to have some influence on ionization by collision of electrons with molecules, and on the electric strength of a gas, but this latter point does not appear to have been investigated previously. It is now well known that when free atoms or molecules are bombarded by an electron stream the apparent cross-section offered to the stream is not constant. The effect of the reaction between the wave field of the electron and the electric field of the molecule that it approaches varies with their relative velocity. This effect was discovered by Lenard in Heidelberg as long ago as 1894 and has been the inspiration of much research. In several cases the apparent cross-section rises and falls again as the speed is increased. Ramsauer discovered the remarkable behaviour of the monatomic gases, that has since been found characteristic of the paraffins and many others.*

When a molecule is spherical, the mean free path is a function simply of the diameter of the molecule and the gas pressure. When there are free electrons present in a gas, as there always are in air, then as soon as an electric field is applied they move with increasing velocity up the field until they collide with a molecule. Because they are so much smaller than molecules the electrons have a mean free path that is $4\sqrt{2}$ times greater than the gas kinetic free path, provided that the cross-section of the molecule is the same for electron collisions as it is between molecules. If, therefore, the probability of ionization of similar molecules by collision depends upon the energy of impact, all gases with molecules of the same size might have the same electric strength; but they have not. It depends on the movement of the electron in the electric field of the molecule, and therefore on the shape and the internal arrangement of the atoms of the latter. Stephenson found that when the breakdown strength of each gas was plotted against its mean free path the gases he had examined fell into two well-marked groups.† The significance of their separation is seen better by taking as abscissa the reciprocal of the electron mean free path. In the upper group there are, in ascending order of electric strength, hydrogen, oxygen, air, nitrogen, carbon monoxide, nitrous oxide, and ammonia. In the lower group are methane, carbon dioxide, and the paraffins up to pentane. The electric strength of a gas in the upper group is exactly twice that in the lower, or the mean free paths of gases in the two groups having the same electric strength are in the same 2 : 1 ratio.

This new fact in the passage of electricity through gases has still to be explained. It can only occur through a difference in the electron mean free paths. As Darrow has pointed out, the ratio of the electron mean free path to the molecular mean free path should be written $4\sqrt{2}(\sigma_0/\sigma)$, where σ_0 is the geometrical cross-sectional area and σ the area of the effective field of the molecule offered to the electron stream.‡ On this view the ratio of the ordinates of the various curves of gases having the same free path is the ratio σ_0/σ, or its inverse value. It provides, therefore, a new means for comparing the electric fields of molecules, when the ionization is so intense that the gas is on the point of breakdown. In either group the product $\epsilon_0 l$ is constant, and this product is the energy acquired by an electron between collisions or in traversing a distance l under the influence of the field ϵ_0. For the force on an electron is ϵe and the work done in moving through a distance l is equal to the kinetic energy $\frac{1}{2}mv^2$ of the electron at the end of its free path, i.e. the energy of collision. Thus on either of the lines breakdown occurs when the electrons have the *same collision energy*, in gases as unlike as hydrogen, oxygen, or nitrogen, or in the other group as carbon dioxide and the higher paraffins. Since there is the same number of electrons in the breakdown path it follows that any difference in their collision energy can only arise from difference in their length of travel, and this again depends on the cross-section of the molecular field offered to the electron. This area σ is greater or less than the geometrical section σ_0 of the molecule, and the ratio σ_0/σ is an indication of the magnitude or range of the molecular field of force. For fast electrons that pass through the molecule the area of section of a molecule has been found to be the sum of the areas of the constituent atoms, and is only a small fraction, 1 or 2 per cent, of the gas kinetic cross-section. For slow electrons that are more easily deflected by the molecular fields, the ratio may also fall well below unity as if the molecule had little influence on the passing electron. At some intermediate values the ratio may be much greater than unity. This difference between the electron free path and that calculated on the $4\sqrt{2}$ convention is the most probable reason for the divergence of the lines. It remains to consider why the ordinates, or abscissæ, of the one group should be so closely double those of the other. The simplest explanation is that an electron following a path that just misses a molecule must go twice the free path before it can strike another, and in doing so it acquires twice the energy that it would have had if it had been stopped by the first molecule. But if all gases in a group require the same energy

* See Reference (8).

† See Reference (9).

‡ *Ibid.*, (10).

of collision and ionization when breakdown is about to occur, it follows that only half the field is necessary for electrons that travel twice the first distance. If there are two gases having the same mean free path but with the electric strength of one half that of the other, the most probable cause of the difference in their electric strengths is that the electron mean free path of the one is twice that of the other, and twice as great as would be expected on the usual kinetic theory of gases. We thus have an explanation of the results based on inspection of the movement of an electron through a uniformly distributed and stationary crowd of obstacles, a kind of electrical skittles, for in spark discharge the speed of the electrons is so great that by comparison the gas molecules are at rest.

The electrical breakdown of a number of other gases was examined in order to see whether the results gave a more random distribution or whether they still fell into groups similar to those first obtained. It is found that they do and that they lie on lines like the ribs of a half-open fan. Gases like carbon tetrachloride are very strong electrically. Then follows a group of chlorides, then the hydrogen group that now contains the alcohols, then the paraffins, then the monatomic gases, then benzene and ether which have very little electric strength, and lastly acetone, that breaks down in the smallest fields that could be applied. The ordinates of these proceed in regular integral steps, and, just as there is stepped ignition of explosive mixtures by electric sparks, so here one finds the action that leads to the passage of sparks to proceed by stepped ionization according to the type and magnitude of the electric field of the molecules.

According to all the experimental evidence the passage of an electric spark through air or an explosive mixture is complete before the molecules begin to move and, therefore, before chemical combination begins. The time-lag in gaseous explosions supports this. The spark leaves in its track a number of molecules ionized by collision as the electrons pass. The manner in which chemical combination between these activated molecules subsequently proceeds depends on the relative numbers of oxygen and combustible molecules. Steps occur in the critical curves of ignition only when the ratio of these passes through certain values depending on the number of oxygen atoms required for complete combustion,* but the essential point is that ignition of any gas by a spark is determined by the ionization that occurs during its passage and later chemical combination, and not by the heat generated in the spark.

It may in the future be possible to calculate by wave mechanics the complex molecular fields and their appropriate cross-sections, and the observations described here should provide material by which to test such theories. Their present practical value is in the information that they give of the relative magnitudes of the electric fields of molecules, some of which are used in insulating compounds. They open a wide field for the consideration how and why the substitution of one atom for another in chemical compounds affects so profoundly their electric breakdown strength, a question of direct interest to all concerned with insulating materials. The substitution of a chlorine atom for a hydrogen atom increases the electric strength. So does the addition of an oxygen atom to a paraffin. The addition of an oxygen atom to carbon monoxide halves it, but carbon monoxide is an anomalous compound, the bane of organic chemists. Benzene again is not a strong gas electrically, but phenol, that is formed by the addition of an oxygen atom to a benzene molecule, is the source of the strong bakelite compounds. The influence of change of pressure of vapours near condensation on their electric strength is another field of research that should throw light on the changes in molecular electrical fields of gases during their transition to the liquid state in strong applied fields.

* See Reference (11).

Liquids.

It is not to be expected that such clear-cut differences should be found in liquids as in gases, for the mechanism of electrical breakdown in liquids is probably not by collision but by an action resembling intermittent electrolysis.

Many liquids, like water, are conducting dielectrics. If they were perfect conductors they would be opaque. The theory of the behaviour of a conducting dielectric in an alternating field was given by Maxwell* and extended by Heaviside.† It was the subject of a most interesting paper by Sir Oliver Lodge on "Opacity"‡ and is now found in some advanced textbooks. In the movement of charge in liquids and solids as distinct from gases there is an elastic term, and it is to the modification of the elastic forces that we must look first for an explanation of electric breakdown. The paraffins that when in gaseous form have a relatively low electric strength, have a high value as liquids. The electric strength of liquid chloroform is higher than that of liquid pentane, but not in the same ratio as their vapours. It may be that in some cases the shapes of the molecules have even more influence on electric strength when they are packed as closely as they are in liquids. There is here again an unexplored field of research on a comparison of the electric strengths of gases and their liquids, especially at low temperatures. Under the influence of an applied field the molecular structure is distorted, as shown by electric double refraction. To tear an electron from a molecule by a static field requires an intense gradient, and the phenomena of dielectric hysteresis which begin to be important in liquids show that there is an internal field of mutual action long before breakdown. It is by this interaction between the induced charges on polarized molecules and the field, whether it is a linear displacement or a rotational effect as on Debye's theory, that we can explain most simply not only dielectric hysteresis but the facts of the electrical breakdown of the medium, and it is at least in part the simplicity of action that we desire to find. Dielectric polarization in all the materials examined has two parts, a perfectly elastic component that is transmitted at the velocity of light or electromagnetic waves in the medium, and an effect resembling "elastic after-working" that is the cause of the residual charge observed in all non-homogeneous insulators. A solid dielectric may be strained by a unidirectional field to many times its polarization value in an alternating field,

* See Reference (12). † *Ibid.*, (13). ‡ *Ibid.*, (14).

and, once polarized, it behaves as if its molecules were dipoles. Attempts have been made to find whether molecules of liquids such as oils behave as dipoles, but no standard or simple method has been devised so far, nor have any entirely reliable results been obtained. The following experiment, difficult to repeat, might provide a means of doing this. A quartz rod was suspended in a test tube outside of which was spun another insulating tube on which were two poles connected to a high-voltage battery. There was then a rotating electric field of constant strength passing through the tube; and the rod, because it had dielectric hysteresis and absorbed energy, experienced a torque and followed the field. When, however, the test tube was filled with oil the rod was seen to rotate in the reverse direction. The molecules of oil acted, with a good deal of slip, as gear wheels on the surface of the rod and glass. Unless they were induced or permanent dipoles nothing would happen; they would not follow a rotating field of constant magnitude. Until more is known of the behaviour of a wide range of liquid insulators in strong rotating fields and their induced or intrinsic polarities are compared, there is little hope of the development of a fundamental theory of dielectric polarization covering such liquids as oils.

It is not known why small quantities of impurity in a liquid should have so great an influence on its electric strength or absorption of energy. It would seem to depend more on differences of dielectric constant than on any other factor. In insulating liquids (though not in gases) water, as everyone knows, is a great cause of failure. But pure distilled water with a resistivity of 70 000 megohms per cm cube is a better insulator even than celluloid. It has a high activity as a solvent, yet in oils that are, for all practical purposes, insoluble in water the smallest quantities are known to reduce the breakdown strength in a remarkable manner. This is not caused by the increase in the electrical conductivity of the mixture, for minute carbonized-cotton fibres in such quantity that the oil is black do not necessarily, even with high voltages, cause a disruptive spark to pass. Water particles in an electric field gather to form larger drops, whilst there is a succession of miniature arcs between the ends of the carbon fibres that are extinguished rapidly by the oil. It is not the conductivity of the water or its solvent power that makes it dangerous, but its very high dielectric constant. The action is in two steps. First the particles of water having a higher permittivity than oil are drawn into the strong field between the sparking points and form a partial chain. This can be observed by a microscope. They then act as if a slab or rod of solid dielectric having a much higher permittivity than the oil had been introduced between the poles. This, as is well known, increases the electric gradient in the other part of the medium, and, if the original setting is critical, breakdown follows. A simple calculation shows how small a quantity of moisture is necessary to cause breakdown of oil in this way. In a centimetre cube of oil there would be perhaps 5×10^{21} molecules of oil, having a dielectric constant of about 2. A chain of water molecules having a length l between midpoints of opposite sides would increase the electric gradient ϵ in the oil of the remaining part, for the permittivity of water is about 40 times that of oil. The relation is

$$(1 - l)\epsilon + \epsilon l/40 = V.$$

When $l = 0 \cdot 8$,
$$0 \cdot 2\epsilon + 0 \cdot 02\epsilon = V$$
$$\epsilon = 4 \cdot 5V$$

V is the gradient when no water is present, so that the oil with the water particles will only carry a little over one-fifth of the voltage that the dry oil carries.

The volume in the chain assumed to have a diameter of 5×10^{-6} cm (about the least that could cohere) is $1 \cdot 6 \times 10^{-11}$ cm^3. Thus if all the molecules of water in a unit cube of oil were to collect in such a single chain stretching across $0 \cdot 8$ of the space, it would lower the electric strength of the oil along that path to one-fifth of its dry value, and yet be, on the above assumption, little more than a billionth part of the whole. This is the extreme lower limit. In practice the diffusion of water particles to a point of high electric gradient is slow, and there are rival gradients that dilute the effect.

Plastic Insulation.

There is between liquid and solid insulating materials as there is between gases and liquids a transition stage that is almost as important in underground transmission as the moisture films are for overhead insulation. Paper cables impregnated with oil alone may not, when laid, remain uniform throughout unless perfectly level or under pressure. To prevent this effect, resin is used to increase the viscosity of the compound, and to this certain waxes are added to reduce the conduction current. As previously mentioned, many of the phenomena of conduction in cable insulation suggest that endosmose plays a large part in it. Thus when oil alone is tested a certain current is observed, with oil and paper in equal volumes much less current, and with paper alone less still. Conduction is clearly helped by bodily movement of the fluid and is therefore of the nature of endosmose. Mixing the compound with inert colloids or carnauba wax, the fine crystals of which act as baffles to any movement of fluid, lowers the conduction current to a small fraction of its previous value. The particles, to be moved at all by the field and carry a current, must be ions, for "electricity only moves electricity." Much has been written on ionization in high-tension cables. Dielectric losses are usually regarded as having two components, a true dielectric hysteresis effect proportional to the square of the field, and the remainder interpreted as caused by ionization. The physical nature of this ionization has never been clearly stated. It is a function of the temperature of the compound, and ionization by collision in air cavities or films cannot on the evidence be responsible for so great and uniform a change as that observed. Whatever happens must be looked for in the compound itself and in any charge its particles may acquire. If these are colloidal they can retain a charge from the time of their mixing with the compound, as they do in rubber latex, for example, in which the particles carry a strong negative charge. If they are crystalline the grouping of atoms in the crystal determines whether

there can be intrinsic charge, and it is an open question whether the redistribution of molecular fields that occurs when a substance melts does not cause in the crystalline components an interchange or formation of charge that is only to be observed by the increase in the conduction current in a molten state. The combined electrical and mechanical theory of this movement of fluid through such irregular obstacles as wax crystals is beyond calculation and must long remain empirical.

The electric strength of compound-impregnated cables is more amenable to treatment. Peek's well-known formula $\epsilon = \epsilon_s(1 + at^{-\frac{1}{4}})$, in which t is the time of application after which the insulation breaks down at a gradient ϵ, and ϵ_s is the gradient at which it breaks down after an infinite time, can be replaced by the formula $\epsilon = \epsilon_s/(1 - e^{-bt})$, for which a reason has been given based on the existence of a quasi-viscosity term in the voltage equations.* In both formulæ ϵ is equal to ϵ_s when t is infinite, and to infinity when t is zero, but neither formula fits exactly the curve of experimental results. The effect is probably a complex of "electrical afterworking" and molecular friction or "stiction," and there is a further physical action that does not appear to have been previously considered. The molecules of most of these oils are now known to be elongated or chain-shaped. When such a body is shaken or moved rapidly to and fro it takes a position offering the least resistance to motion; that is, with its longer axis along the line of flow, like iron filings in a magnetic field. There is then in a viscous insulator a relatively slow orientation of its longer molecules into the line of the alternating field. This increases the electric polarization as if the field were raised, and may have a marked effect on the time taken for breakdown to occur and on the disruptive voltage. It imitates the behaviour of dipoles and might be included in dipole theory. Such a mechanical molecular effect would explain why the change of fluidity with temperature has so marked an influence on the power lost in the dielectric; this influence is difficult to account for on a plain electric theory. At very low temperatures the dielectric loss is small, since everything is held rigid. As the temperature is raised the material becomes plastic and molecular orientation or movement is possible. At higher temperatures this stictional hysteresis is less and the loss falls, but conduction currents then begin to be important and eventually are so great that the insulation breaks down. The nature of this conduction current due to the movement of ions is of the first importance in cable making. If, as suggested above, it is electromechanical or endosmotic in origin, it would explain the drift of modern high-tension cable practice, and a proof that wax crystals act as mechanical rather than electrical baffles to the movement of ions might provide a reasoned basis for further design. It is extremely interesting to observe under the microscope the motion of fine particles suspended in an insulating liquid to which an alternating field is applied. The amplitude of motion in the line of the field and the orientation of elongated particles are readily observed and by this method the change of motion with the temperature of the compound can be followed. It is not a quantitative method, but it enables a picture to be formed of what goes on in paper-cable insulation as the temperature is raised.

* See Reference (15).

Solids.

When a unidirectional electric field is applied to a solid dielectric there is an instantaneous polarization corresponding to the true dielectric constant, followed by a slow increase—in some substances to 100 times the initial value. On short-circuiting the electrodes there is an instantaneous discharge and a relaxation of the residual polarization to zero, which may take several days to complete. This is common knowledge. What is not so well known is that the quantity discharged is, in effect, twice that put in.* If a cable or condenser is charged at a steady d.c. voltage and then short-circuited, the area of the residual current/time curve in the latter case is twice that observed during charge. At any instant the quantity Q in the cable is the product of the capacitance C and the voltage V, and, because of the internal movement of charge, C is variable. The current $i = dQ/dt = VdC/dt + CdV/dt$. During charge at constant voltage the second term is zero, or $Q_c = \int idt = VC$, where C is the apparent capacitance corresponding to the residual polarization at the end of charge. During short-circuit both C and V vary. C starts from the maximum and falls to zero, and V also falls to zero. Thus $Q_d = \int CdV + \int VdC$, and since C and V go through identically the same range of values during discharge as in charge the two terms are equal and $Q_d = 2Q_c$. The energy received during charge is VQ_c and that returned on short-circuit is $\frac{1}{2}VQ_d$, and since $Q_d = 2Q_c$ these are equal. Since experiment shows this to be the case, the residual polarization in condensers is a perfect example of *Elastische Nachwirkung*.

On the electron theory of conduction the reason for the doubling of quantity on short-circuit is as follows: While the applied voltage is maintained there is a field from the positive to the negative pole and an extrusion of negative charge on the latter. The opposing internal field of polarization grows until it is in equilibrium with the applied field, and the charging current falls to zero. When the condenser is short-circuited it leaves the residual polarization. The direction of the acting field in the medium is therefore reversed, and, if it could move quickly enough, a negative charge equal to that on the old negative pole would at once appear on the original positive pole. The quantity passing through the galvanometer on short-circuit is therefore twice that passing during charge, since Q_c is taken out and restored in the reverse direction. This simple explanation of a result that has been questioned or otherwise reasoned away explains also the behaviour of a dielectric ellipsoid suspended in a field of force. If when the polarization is steady the field is reversed the forced change of polarization can be followed by observing the change of frequency of swing, as I have shown elsewhere.†

It is not possible to observe directly any electrical movement inside solid insulators except by electron-stream or X-ray diffraction patterns, and it would be worth investigating by X-ray spectrography whether there are visible changes in the molecular configuration of insulating materials when they are placed in strong

* See Reference (16).

† *Ibid.*, (17).

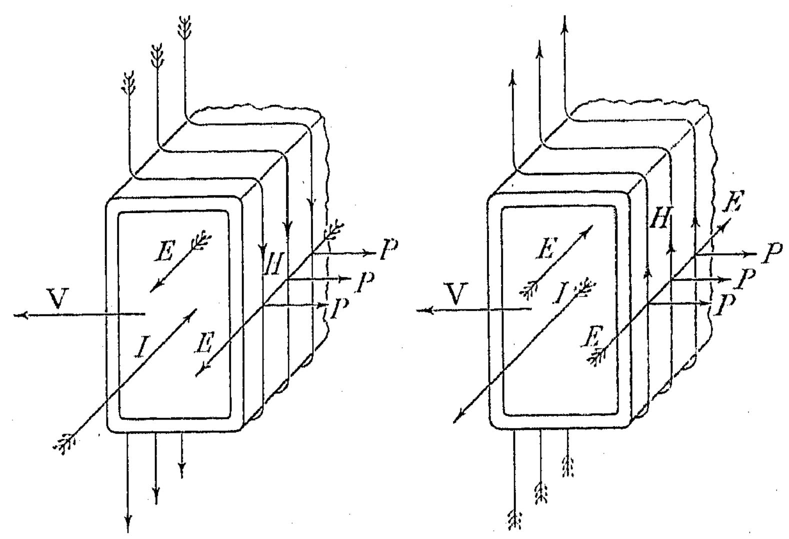
electric fields, as there are in rubber when it is stretched. What happens can only at present be inferred by the changes in the external circuit, and we have therefore to proceed by observation of electric strength, dielectric constant, and conductivity. Of these the first is much the most important.

There are some simple relations that appear to govern the electrical breakdown of solids. The work done in breaking down a solid dielectric is in general constant for that material and is independent of the thickness.* As a consequence of this and the fact that in a unidirectional field of force the polarization of an isolated dielectric has a term independent of the intensity of the field, the relation between thickness (τ) and the breakdown voltage (V) should be simply quadratic, namely $\tau = aV + bV^2$. This is found to hold over a surprising range of values and materials, with differences of only a few per cent between actual and calculated figures. The first term is that which shows the influence of hysteresis. For this reason it might be expected that it would be the linear term in the quadratic that would be most modified in high-frequency fields. This has not yet been explored, and it would be a useful piece of work to do. All insulators break down at a lower voltage as the frequency of the field is raised, when the electrical movements that are necessary to establish equilibrium in a field of force are slower than the change of the field, much in the same way that it is easier to upset by a sudden shake a person who is not quite ready for it and who has not time to brace himself for the effort of resistance.

Insulators as Transmitters of Energy.

I have left to the last a consideration of the real function of insulation, that is, to transmit energy, for by it alone and not by the wire it covers is the energy of a circuit carried. It is an axiom of mechanics that power is transmitted by the action of a force in a medium causing a strain that is continually relaxing at the point of delivery. In an electric circuit it is the insulation and not the wire that is strained, and therefore, *a priori*, the insulation should carry the energy. The manner in which this is done was first shown by Poynting in 1885 as a consequence of Maxwell's theory of the electromagnetic medium, but it is not yet known by engineers as it should be. Poynting's law states that power is transmitted through a dielectric by the combined action of electric and magnetic fields at right angles to one another. Both fields are necessary. In the case of a concentric cable or overhead line the electric field is radially outwards from the conductor, the circular magnetic field is coaxial with it. The direction of flow of energy is represented by the thumb of the right hand when the forefinger denotes the direction of the electric field, the middle finger the magnetic. The energy transmitted streams through the insulation parallel to the conductor. In an electric motor (see Figure), the energy passes from the insulation of the line to that around the conductors of the winding, to the core, and so to the shaft. It must therefore pass outwards, away from the conductor. The magnetic field around the current is at right angles to the conductor and, in order that the energy flow should also be at right angles to the conductor, and outwards, the electric field must be *along* the insulation *parallel* to the conductor, in the opposite direction to the flow of the current and therefore in the same direction as the induced voltage in the conductors. So that the motor is driven mechanically not by the voltage generated in the copper of the windings (that merely holds up the line voltage and controls the current), but by the voltage generated *in the insulation surrounding the conductors by its own motion across the pole flux.* Apart from some polarization, there is the same voltage induced in the insulation as there is in the conductors, but by virtue of its being a non-conductor only an infinitesimal conduction current flows along it, though energy streams through it freely as it does through the ether of space in radio transmission, or in conveying to us the light and heat received from the sun. The flow of energy is not symmetrical from the wire to the core, for the magnetic field is distorted. There is therefore a difference in the rates of flow of energy on

* See Reference (18).



Flow of energy in a motor armature, according to Poynting's Law.

E = voltage induced. P = power.
H = magnetic field. V = Direction of motion.
I = current.

the two sides of the conductor, and more flows from the side carrying the greater magnetic field. The direction of flow of energy into the core is therefore opposite to the direction of rotation of the armature, as it should be, and as it is in the case of a pulley driven by a belt. Energy is in that instance transmitted from the belt to the driven pulley from the point where the strain on the belt is greater, that is the tight side, to where it is less, on the slack side. The direction of energy-flow is therefore from belt to pulley in the opposite direction to the motion. It flows, as it were, backwards. What actually changes is the state of strain in the belt between it and the molecules of the pulley. Without such a strain no energy could be transmitted. Energy that is not kinetic is static, and electrical energy is transmitted through insulation by means of a static strain that varies from a maximum at the high-tension end of the winding to zero at earth potential.*

It may seem a far cry from this simple though fundamental illustration to the deep problems of insulation

* See Reference (19).

that require the most advanced theory and most patient experiment to solve, but all progress in science has been by the conception of a new and, in itself, simple idea thrown into appropriate form, tested by observation, and revised from time to time to fit new facts. Until, in the case of insulation, a theory has been found adequate to explain the ultimate mechanism of electrical breakdown and the nature of conduction currents in liquids and solids, and to predict the behaviour of new substances whose atomic and molecular constitution is known, the subject of insulation will be much more an art than a science; and it cannot be allowed, by this Institution least of all, to rest in that unbalanced position. There are at present not nearly enough facts known on which to frame a complete and fundamental theory of dielectric behaviour. I have indicated several lines on which investigation might proceed, in the hope that members who are interested in experimental research may help to fill some of the gaps, but it will take many years to do it. The nineteenth century was the age of the machine. If the present century should come to be regarded, so far as electricity is concerned, as the age of insulation made perfect, it will have been a worthy contribution to electrical theory and practice.

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WIRELESS SECTION: CHAIRMAN'S ADDRESS

By S. R. Mullard, M.B.E., Member.

"THE DEVELOPMENT OF THE RECEIVING VALVE."

(Address delivered 7th November, 1934.)

In the first place I desire to thank you for the honour you have done me in making me your Chairman. It is a position I have accepted with great pride and I shall do my utmost to maintain the high standard which has been set by my predecessors in office. I also wish to thank Dr. Hodgson and Mr. Goldup, together with my other friends in the various valve works and elsewhere, for the kind assistance they have given me in the preparation of this address.

It is one of the perversities of science that years spent in patient research may, in the end, yield results of little scientific value and no commercial utility, while the investigation of an accidentally produced, and apparently trivial, phenomenon may have results of great scientific importance, which, when developed industrially, can influence the daily lives of us all.

But it is only the mind trained to careful observation and logical reasoning that has either the desire or the ability to explore these accidentally disclosed by-ways to new knowledge, and it is perhaps fortunate that one of these rare opportunities should have been given to Edison, for it was the curiosity aroused in his mind by an unexpected phenomenon in his early carbon lamps which has ultimately given rise to the thermionic valve of to-day.

This address will deal more particularly with the application and manufacturing development of thermionic receiving valves since the inception of broadcasting. The scope of the address is not intended to cover transmitting valves, as the development of both water-cooled transmitting valves and silica valves has been dealt with by other authors. The early history of the receiving valve is too well-known to members of this Institution to be repeated here; its modern history may be said to begin with the introduction of broadcasting some 13 years ago.

The first valves used in broadcast receivers were the "R" type of high-vacuum tungsten-filament triodes, or valves differing from them only in minor constructional details. Immense numbers of these valves had been used during the War years, but it soon became obvious that further improvements were necessary in order to enable manufacturers to satisfy the growing demand for reliable valves and to meet the rapid improvements in broadcasting and receiving-set design.

The filament heating consumption of the "R" valve was a heavy drain on the largest accumulators which could conveniently be put to household use, and even with this considerable filament energy the available electron emission was small. The filaments were fragile, and the manufacturing losses high, largely owing to the only method then available for expelling the occluded gases from the electrodes during pumping, which was by electronic bombardment from the filament. This tedious and unsatisfactory method was soon superseded by the process of heating the electrodes by an induced high-frequency current during or after pumping. This process served a double purpose: it first drove out the occluded gases and then evaporated a small quantity of magnesium, which removed the gases thus liberated. Here it is interesting to note that the development of the triode itself as a transmitter, made readily available the large high-frequency power necessary for this improvement in valve technique.

The manufacturers of incandescent lamps, who, by reason of their factory plant and pumping technique were also the early valve makers, knew that the introduction of thoria into tungsten improved the life and strength of lamp filaments. On using these thoriated filaments for valves they found, to their surprise, that it was possible to obtain considerably greater emission from them than from pure tungsten, but the occurrence of this emission was erratic and its duration short.

This phenomenon was investigated very thoroughly in America by Langmuir and his co-workers, who developed a theory of the operation of the thoriated filament which satisfactorily explained the observed facts. Langmuir pictured the filament as a miniature chemical factory, in which the thorium dioxide is reduced to thorium in the body of the filament and thence transferred to the surface, where it adheres very firmly to the tungsten and forms a highly emissive layer. This layer is very sensitive to traces of gas, and the rate of production of the thorium metal varies rapidly with temperature; an extremely good vacuum is necessary, both for its initial activity and for the maintenance of this activity during life.

The chief danger from low vacua lies in the deactivation of the filament by oxidization of the metallic thorium on its surface, and this was the main reason for the development of the high-frequency heating process and the magnesium "gettering." The partial reduction of the filament to tungsten carbide by glowing in hydrocarbon vapour is also an effective method of preventing deactivation, the effect of both the carbon and the magnesium being to maintain an oxygen-free atmosphere in the valve throughout its life, and to assist in the reduction of the thoria.

Although this thoriated tungsten ran at a considerably lower temperature than pure tungsten, it was subjected

during activation to much higher temperatures, becoming in the process as brittle as an ordinary tungsten filament. This brittleness was accentuated by the use of very fine filament wires, which the greater emissivity of thoriated tungsten made possible.

Nevertheless, clearances between grid and filament were reduced and the slope of valve characteristics increased, and thus a big step forward was possible in circuit applications.

The demands, however, for still further improvements in valve characteristics, and also the desire of the manufacturers to improve the reliability of valves in service, led to a more careful consideration of work done years previously with oxide-coated filaments.

In the early days of this century, Wehnelt discovered the very great emissive properties of the oxides of the alkaline-earth metals, and for a long time platinum coated with lime was the chief source of electrons for laboratory work. A cathode of this type was used by Richardson for his original work on thermionics, and the earliest diodes and triodes made by Round and Lieben and Reisz also had this type of cathode. It was only neglected in favour of tungsten because in the War days it was not possible to make a hard valve with this cathode, and soft valves were erratic in performance and in life.

The needs of the Services could be satisfied only by a valve suited to mass production which operated simply and uniformly in action. The Wehnelt cathode had, however, not been forgotten. Improved methods of coating platinum with barium and strontium oxides were developed in America, and these, in conjunction with cleaner materials for the other electrodes and improved methods of exhaust, yielded cathodes which operated at lower temperatures and which had lives longer than any anticipated by the most optimistic a few years previously.

Some disadvantages still remained; platinum wire was at that time very expensive and, except in the larger diameters, mechanically weak; even the larger diameters tended to re-crystallize and "off-set" during life. Further, the oxide coating was extremely susceptible to atmospheric influences, and had to be very carefully protected in the open air and even in the bulb before evacuation.

In 1924 another method of producing oxide-coated cathodes was developed—that known as the vapour process—by which not only was the task of the valve manufacturer made very much more simple, but also a far less fragile cathode was obtained.

This process consists of providing an oxidized metal cathode in the valve and surrounding this cathode, after preliminary evacuation, with the vapour of metallic barium. The source of this vapour may be either barium metal or a compound such as barium azide (BaN_6) which is reduced to the metal on heating in vacuo.

The cathode is generally of tungsten, although practically any metal with a sufficiently high melting point may be used, such as nickel, iron, or platinum.

This vapour process does not render the tungsten brittle, as the filament is not subject to high temperatures during activation. It is obvious that the amount of barium oxide on the finished cathode can be closely controlled by the amount of oxide of tungsten or other metal initially present on the surface of the filament, the reaction between this oxide and the barium vapour being almost quantitative. Further, the barium oxide is formed on the cathode *in vacuo*, and no atmospheric influences can damage it.

There are, however, some disadvantages, even in so simple and effective a method, and practically all of these arise from the large barium mirror produced on the walls of the valve. This, by the nature of the process, is unavoidable and in many valves is unimportant, but in certain types it introduces objectionably large inter-electrode capacitances, and in others, such as power rectifiers and large-output valves, it reduces the effective heat radiation. It is therefore necessary in some types of valves to use the pasted Wehnelt cathode. Thus once again Wehnelt's original cathode, discovered in 1904, has been brought from its retirement and with the assistance of modern manufacturing methods has been used to satisfy the needs of a gradually improving technique in valve and receiver design.

The Wehnelt cathode has also rendered possible the indirectly heated cathode, in which a metal tube is coated with an emitting layer and heated by a filamentary heater insulated from it electrically by a refractory material such as aluminium oxide or magnesium oxide. These cathodes permit alternating current to be used for the heating of the cathode and avoid the inconvenience attached to heating by accumulators.

Experiments to this end had been made for several years, and the modern indirectly heated cathode differs only in detail from the early McCullough cathode, although a great deal of work has been necessary to bring the original design to the present state of perfection. The indirectly heated cathode is an equipotential surface; it carries no heater current and thus there is no potential gradient along its length. This cathode is becoming more generally used, and it is only the lack of electric supply mains in so many dwelling houses that maintains the popularity of battery-heated valves. Fig. 1 gives the constructional details of such a cathode; (*a*) shows the heater, (*b*) the insulator, (*c*) the cathode, and (*d*) and (*e*) how the three components are assembled.

The oxide-coated cathode, whether made by the paste or by the vapour process, is a continuously-operating chemical factory, in some ways similar to the thoriated tungsten cathode, but different in some processes in that temperature alone is not responsible for activation. Full activation depends upon the value of the anode voltage during ageing, and this shows that the action is partly electrolytic. Barium is generated during use and forms on the cathode a layer which is the actual electron-emitter.

Although paste- and vapour-formed oxide-coated cathodes are similar in general operation, there are some striking and so far unexplained differences. Paste coatings can readily be made on platinum or nickel cores, but not easily on tungsten cores. On the other hand, the vapour process makes an excellent emitting surface on tungsten cores, but the working temperature is slightly higher than that of pasted cathodes.

In the paste process it is advantageous to use a mixture of barium oxide and the oxides of strontium or calcium.

The reason for this is so far only a matter of conjecture. It may be pointed out that valves produced by the vapour process are not easily made with mixed oxides, but give the best results with barium oxide alone. It is possible that the solution of the problems presented by these differences may open the door to increased efficiency in oxide-coated cathodes, but, although prophecy is dangerous, it is unlikely that any very great reduction in operating temperature will be made; the reason being that the minimum energy which it is necessary for an electron to possess, before it can leave an emitting surface, is well known in the case of all likely emitting materials, and there is no indication that any remarkable lowering of this energy barrier will be achieved in the future. The cold cathode, i.e. a cathode operating at room temperature, will therefore be something very different should it ever arrive. There are possibilities

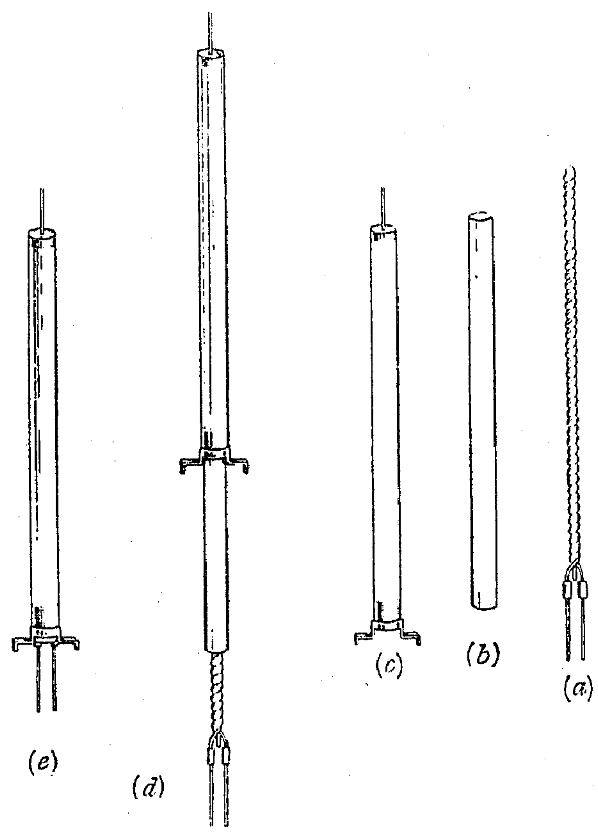

FIG. 1.

in cold cathodes which rely on an external source of radiant energy, such as light, especially if effective use can be made of ionization and secondary emission.

The Table gives an indication of the advance in efficiency represented by cathodes which have been used since the War; a life of 1 000 to 1 500 hours is postulated for various cathodes.

I have so far confined my remarks to the influence of the cathode in valve development. Side by side with this there was progressing the technique of high- and low-frequency amplification. Cathode development considerably modified the technique of receiver circuits, the new circuits suggested other new valves, and each reacted on the other.

With the advent of the thoriated-filament valve, what may be termed the "War" technique was superseded and there appeared for the first time recognition of the necessity for amplifying valves of large power output, the forerunners of the extremely efficient output triodes of the present time. The development of radio-frequency amplification led to the introduction of neutrodyne circuits, in which the known capacitance defects of triodes were eliminated by an additional balancing capacitance, thus overcoming the difficulties of coupling between the input and output circuits. This method had its defects; for instance, it was practically impossible to "neutralize" completely over a wide range of frequencies. This attempt by the circuit designer to produce stable cascade amplification with triodes was soon rendered obsolete by a valve of entirely new design.

In this valve, the screen-grid tetrode (introduced in 1927), the grid-anode capacitance was made so small that it was possible to use tuned circuits of low decrement and at the same time to obtain stable amplification, whereas, with triodes, circuits were often made deliberately inefficient in order to obtain stability, while giving only about one-hundredth of the amplification attainable with the screen-grid valve. The screen-grid tetrode thus became established, and the long-known triode defects were eliminated.

It was appreciated that the high differential anode resistance of the tetrode would make it an ideal output valve, were it not for the negative-resistance portion of its characteristic. The introduction of a fifth electrode between the anode and the auxiliary grid enabled the high differential resistance to be maintained, while, by

TABLE.

Filament	Surface temperature	Efficiency	Emissivity
	°K.	milliamps. per watt	milliamps. per cm^2
Pure tungsten ..	2 500	3–4	200–300
Thoriated tungsten	1 800–1 900	33	700
Barium-oxide on tungsten core	about 1 000	100	500–600
Modern pasted nickel ..	about 850	120–125	about 500

preventing secondary emission from its two neighbouring electrodes, it eliminated the dynatron or negative-resistance portion of the characteristic.

In Fig. 2 the well-known tetrode and pentode characteristics are shown. The anode current first increases with increase of anode voltage in both cases, and if this voltage is low there are no secondary electron effects. With an increase of anode potential, secondary electron emission from the anode (in the case of the tetrode) becomes marked, resulting in a decrease in anode current. As the anode potential approaches that of the screen, there is a smaller collecting effect of secondary electrons from the anode, and a tendency for the anode current again to increase. A further increase in anode potential results in an increase in anode current until saturation is reached. In the case of the pentode, where a grid is interposed between the screen and anode, secondary-emission effects are eliminated and no decrease in anode current occurs. The introduction of the pentode was as great a step forward in low-frequency

amplification as the screen-grid valve had been in high-frequency amplification, and the pentode has superseded the triode in the output stage of most modern receivers. It is interesting to note that the constant-current characteristics of the pentode are simulated in the triodes used for Class "B" amplification. The great sensitivity and comparatively large output of the pentode type of valve gave improved volume and saved the listener a complete low-frequency stage. More recently, double pentodes for quiescent push-pull have been developed. Their application is identical with that already described, but the two pentode elements are contained in a single envelope.

About the time of these developments, self-contained receivers, with loud-speaker and amplifier in the same cabinet, were becoming increasingly popular, and the microphonic noise caused by the mechanical reaction of the speaker on the valve bulb presented another problem to the valve manufacturer. Many devices for cushioning the valves and protecting them from acoustic

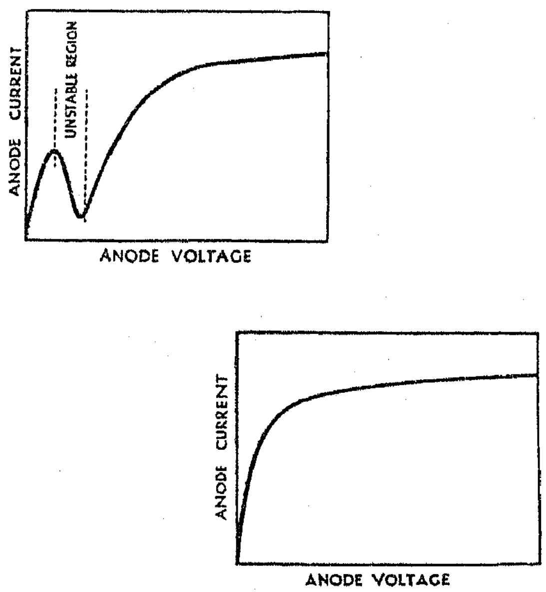

FIG. 2.—Comparison of anode-current/anode-voltage curves for screened tetrode and screened pentode.

disturbances have been tried. In addition, the whole inner assembly of the valve is now locked together and also to the bulb to form a rigid unit.

From the days when transmitter spark discharges gave rise to charges on the walls of the Fleming diodes and audions, it has been found advantageous to screen electrostatically the whole receiving valve from external disturbances. The first method was to surround the valve with an earthed metal can; this method was followed by that of spraying on to the exterior of the glass envelope of the valve a conducting layer of zinc or copper, usually connected to the cathode. This form of protection is now in general use for all receiving valves which may be affected by stray high-frequency potentials. A further advantage of this metallization is that inter-electrode capacitance between anode and grid is reduced and made uniform.

Transmitting stations of very much greater power were being built, and, in order to listen in comfort to the local station on a receiver sufficiently sensitive to receive distant stations, a volume-control device became necessary, capable of adjustment over a wide range of sensitivity without otherwise influencing the efficiency of the receiver. Volume-controls or attenuators of the type used in connection with line telegraphy and telephony offered one solution, but these are both expensive and unsuitable for valve receivers. The so-called "variable-mu" valve is now universally adopted for this purpose. It is obvious that a means of regulating the sensitivity of a receiver is readily available by the variation of the grid bias of the high-frequency valves, the sensitivity decreasing as the grid is made more negative. In the variable-mu valve, the shape of the characteristic is such that by varying the steady negative grid-potential the amplification is uniformly and gradually diminished, and modulation distortion is reduced to a minimum. Any method of controlling amplification which depends upon the negative potential of the control grid needs very little energy and can readily be made automatic, the magnitude of the signal itself determining the grid potential. The practice now general is that the rectified and smoothed carrier-wave maintains a steady potential

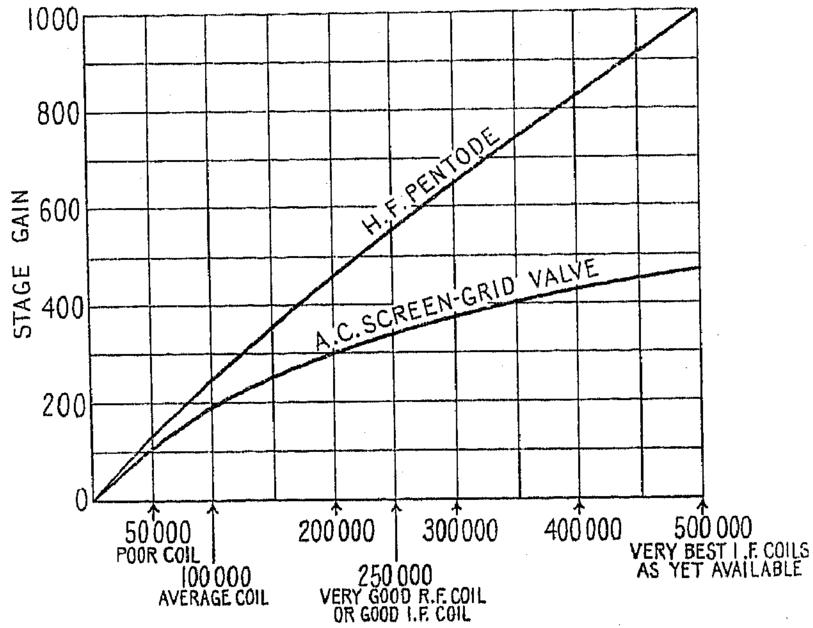

FIG. 3.

at the grid return leads. A strong station yields a large negative bias and diminishes the amplification of the receiver, while a weak signal produces practically no diminution in amplification. A further refinement is the so-called "delay" action, by which signals up to a certain strength have no effect on the amplification. This effect is produced by biasing the rectifier diode which yields the controlling voltage, and has the advantage that a rapid control of bias by signal is possible, thereby rendering the output much more constant over a greater range of input voltages.

Another development in high-frequency amplification is the screened pentode. When the electrical characteristics of the pentode were fully appreciated, it was desired to apply them to high-frequency amplification. The combination of internal screening (which rendered capacitance "feed-back" negligible) with the pentode characteristic of high and constant internal differential resistance, produced an amplifying valve of great uniformity and unrestricted anode-potential swing. It was then possible to utilize signal and intermediate-frequency tuned circuits of high impedance and good power factor, without introducing difficulties in the

amplifying valve. The curve shown in Fig. 3 indicates the increased stage gain possible by employing screened pentodes. It will be observed that the comparatively linear relationship between load impedance and stage gain makes it possible for this class of valve to take full advantage of each and every improvement in coil efficiency.

A further development of receiver design led to the appearance of yet another group of multi-electrode

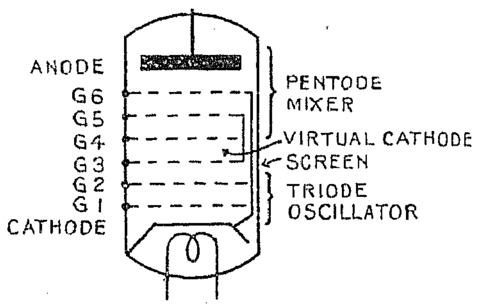

FIG. 4.—Schematic diagram of octode.

valves, which came about in the following way. The early supersonic-heterodyne receivers were unsatisfactory because of difficulty of control and tendency to radiate. After a brief period of favour, they were eclipsed by receivers equipped with neutralized high-frequency amplifiers. With the development of specialized valves and better quality of tuning units, however, supersonic-heterodyne receivers returned to favour on account of their high selectivity and simplicity of operation. In these receivers the essential modulation of the received signal by a locally generated oscillation of slightly different frequency can be carried out by means of a separate generator, exciting the first detector or modulator, in which is produced the "beat" or intermediate frequency. There are several methods of achieving this result in one valve, and the best solution when tetrodes or pentodes were used was the method known as "cathode coupling." In this method the problem of energizing one electrode from two high-frequency sources simultaneously, without undesirable

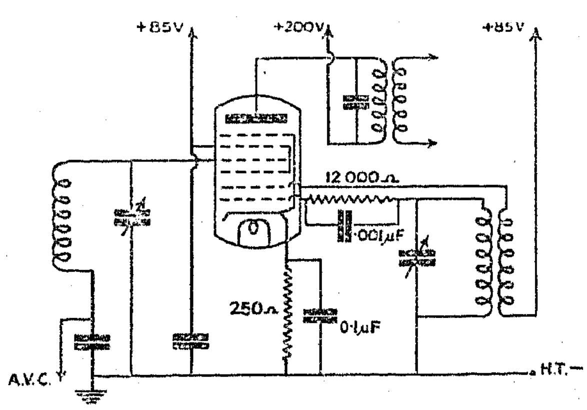

FIG. 5.—Frequency-changer circuit using octode.

reaction between the sources, is solved by a circuit in which the cathode is not "earthy," the impedance from cathode to earth being kept small. The earth is then the junction between the signal and local-oscillator circuits, and the coupling between them is only the grid-cathode capacitance of the valve. The efficiency of this arrangement is low, and it is not possible to use automatic volume control with a self-excited frequency-changer of this type.

Attention was then drawn to a method of control to which the name of "electron-coupling" was given. This, in a frequency-changer, is the means of controlling an electron stream successively and independently by two systems of control electrodes; the first generating the local oscillations and premodulating the electron stream thereby, and the second system again modulating the same stream at signal frequency. With suitable non-linear characteristics the result is a current of "intermediate frequency" in the anode circuit.

The pentagrid, the earliest of such valves, consists, like all of its successors, essentially of two valves in series. The cathode and next two grids form a triode oscillator. Surrounding this system are two screen-grids with a control grid interposed, and an anode. The triode current does not, therefore, all pass to the triode anode; part passes through to the anode of the second valve system, which is in effect a screened tetrode. Capacitance effects between the triode generator and the tetrode are purposely made as small as possible. The electron stream through the triode generator is

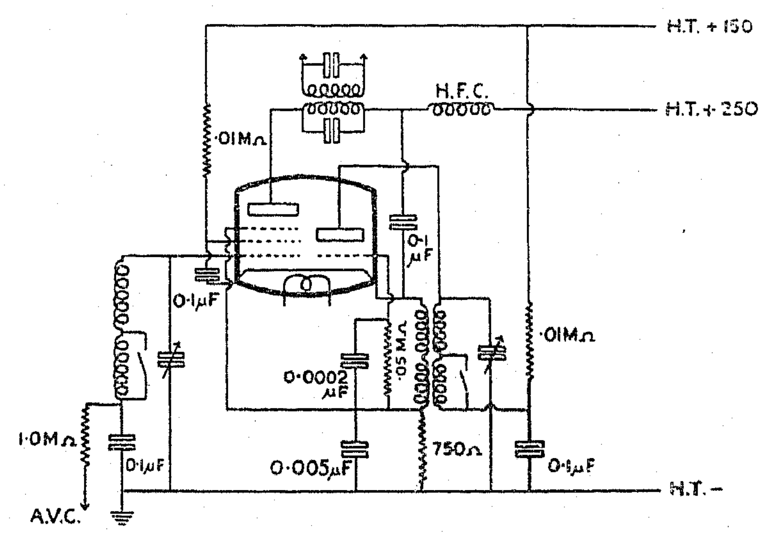

FIG. 6.—Frequency-changer circuit using triode-pentode.

modulated so deeply that it is reduced to zero over part of the cycle. In the tetrode this modulated current is again modulated by the signal, and the resultant current reaches the anode of the screened tetrode. The anode circuit is arranged to amplify the "intermediate frequency" and pass only this component through the succeeding stages of the amplifier. The efficiency of these valves is measured by the "conversion slope," which is the ratio of the intermediate-frequency current to the input signal voltage. With deep modulation of the triode, the "conversion factor," i.e. the ratio of conversion slope to static tetrode slope, may approach unity, thereby enabling the working anode current to be kept low, with a corresponding reduction of valve noise.

The advantages which the screened pentode had been found to possess over the tetrode have led to the adoption of a pentode in place of a tetrode for the modulator portion of electron-coupled valves. The result of this combination is the "octode," and it marks the limit which multiplicity of electrodes has so far reached. As a result of the electron-coupling principle, considerable circuit simplification is effected, while radiation is reduced to a negligible amount. Fig. 4 shows a schematic diagram of the octode in which the various electrodes are

numbered and bracketed to indicate their respective functions. Fig. 5 shows the same valve included in a typical frequency-changer circuit. The efficiency of the arrangement is good, and the variable-mu characteristics of the pentode portion of the arrangement

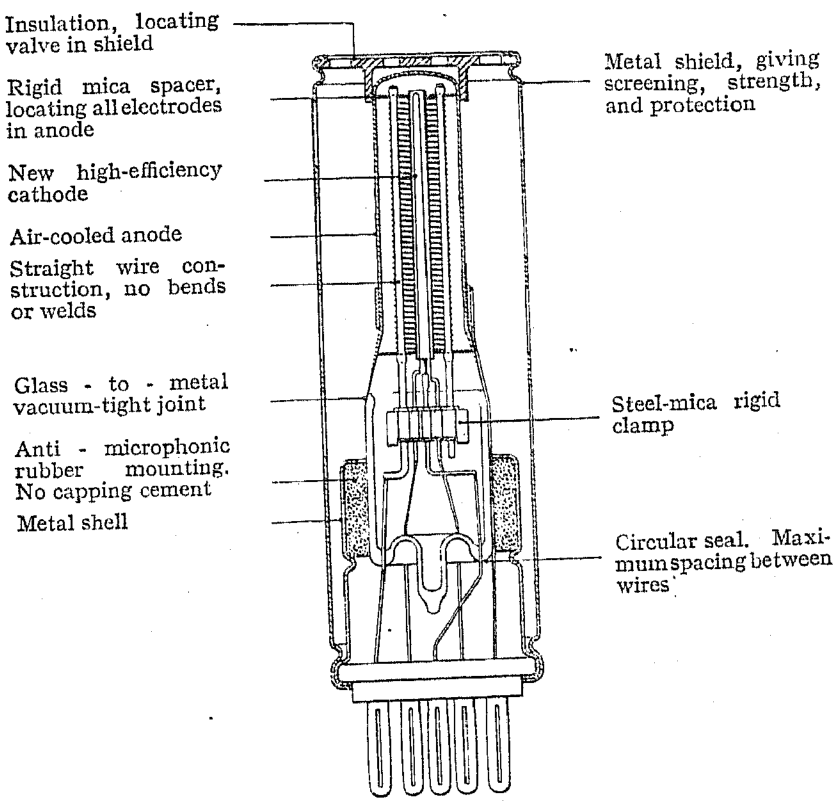

FIG. 16.—Catkin-type triode valve.

greatly improve the effectiveness of automatic volume control.

As an alternative to the electron-coupled frequency-changer, some engineers favour the triode-pentode, which comprises a small triode for use as oscillator, and a variable-mu high-frequency pentode mixer, having

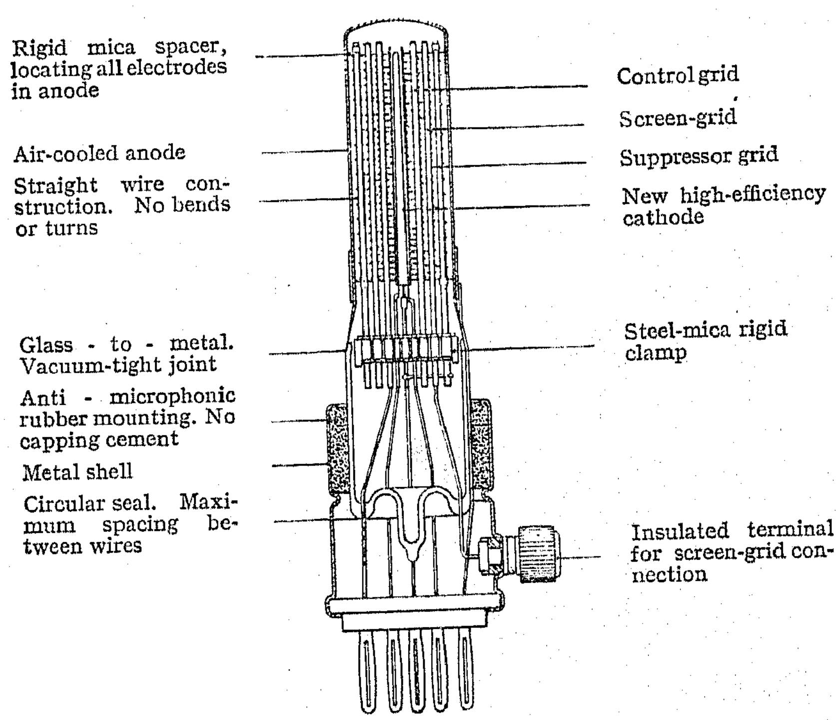

FIG. 17.—Catkin-type pentode valve.

a common cathode. In this arrangement, of course, external oscillator coupling is necessary. Fig. 6 shows a practical circuit using the cathode injection system.

Turning to the manufacture of such complex valves, it will be realized that there are many problems almost hourly confronting those in control of the technical work of a valve factory. When one is dealing with eight electrodes, with clearances between some of them of the order of a fraction of a millimetre, and relying

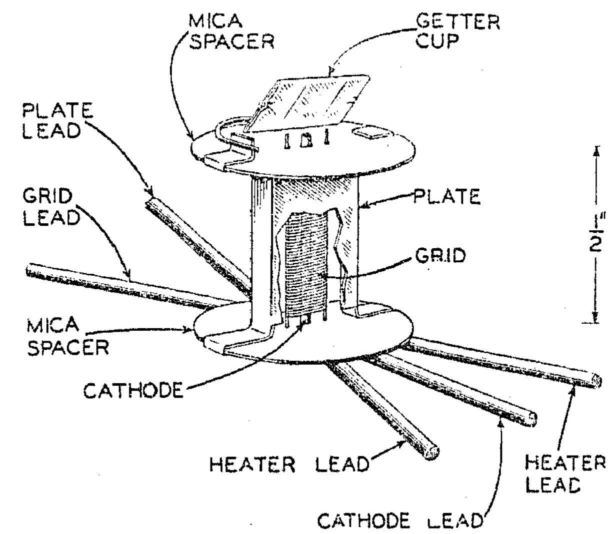

FIG. 18. (Reproduced from *Electronics*, September, 1934.)

on a monatomic film on the surface of a thin wire, for the source of energy, all the electrodes being contained in a bulb evacuated to 10^{-6} mm of mercury, it can be understood that for success with the mass-production methods employed a high standard of efficiency must be maintained. In all this work the skill of the mechanical engineer in the design of jigs and tools has helped in the solution of many of the problems with which the valve maker has been faced.

An account will now be given of some of the changes in construction which have occurred in the period under review.

The valve shown in Fig. 7 (see Plate, facing page 16), which was invented by Captain Round, was manufactured prior to and during the War. It seems difficult for me to

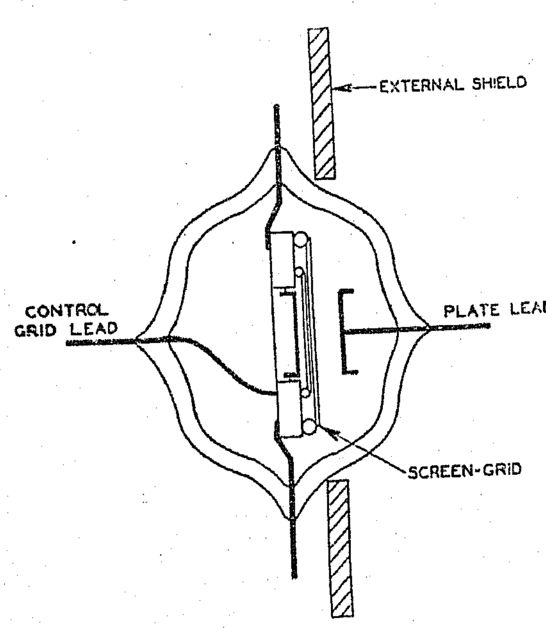

FIG. 19. (Reproduced from *Proceedings of the Institute of Radio Engineers*, December, 1933.)

realize that nearly 25 years have elapsed since I first came in contact with some of his manufacturing problems. In the light of present-day knowledge one cannot but feel that great credit is due to Round for his early

work with these valves. The extension tube at the bottom of the valve contained a small piece of asbestos or similar material, which, when slightly heated, increased the volume of gas in the bulb, and so restored the sharp detector characteristics of the valve.

Fig. 8 (see Plate) shows a modern screened pentode and indicates the considerable changes in form which have taken place during 20 years.

In Figs. 9 and 10 (see Plate) comparison can be made between the foot and electrode supports employed for an

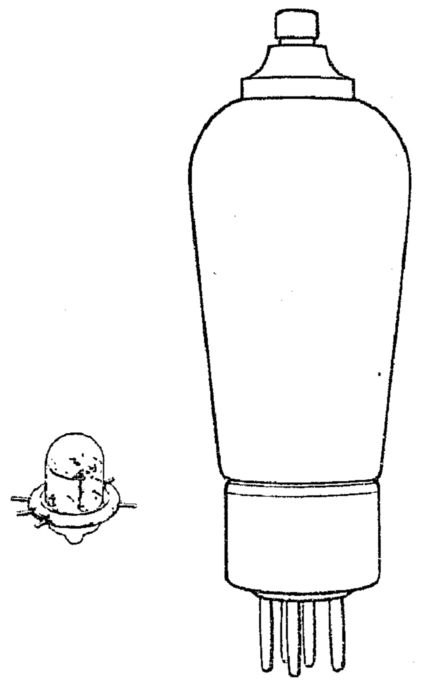

FIG. 20. (Small drawing reproduced from *Electronics*, September 1934.)

early R valve and for a modern battery pentode, while Figs. 11 to 15 are views showing typical constructions as applied to modern battery and mains valves.

A departure from the conventional method of manufacture of small valves has been made in the Catkin type. In this case the metal anode itself forms the major part of the envelope, and obviates the necessity for a glass bulb. Large transmitting valves, where many kilowatts of energy have to be dissipated, have for a considerable time employed the principle of the external metal anode. The principles of construction used in Catkin a.c. types are of general application, and where the power dissipation does not demand an air-cooled metal anode, the other features of design can be used to advantage. Fig. 16 shows the constructional features of a triode in which the anode forms the envelope, and Fig. 17 shows a pentode constructed on the same principle.

Turning now to future developments, the reception of very short-wave signals is becoming increasingly important, as special communication services and television systems tend to use these wavelengths. The generation of waves shorter than a few metres is now readily possible with magnetron valves, but development of means of receiving these short waves has hitherto lagged behind. Valves of minute dimensions, and therefore of very small time-constant, have now been constructed. The mechanical difficulties in making such electrode systems are great, but the valves enable reception to be carried out even at wavelengths of 100 cm or less, with considerable high-frequency amplification. A factor which has contributed to the success of these tiny valves has been the use of transmission-line resonators in place of ordinary tuned circuits, whereby efficient transformer action can be obtained even at a wavelength of a few centimetres.

Figs. 18 and 19 show details of the construction of an indirectly heated triode and a tetrode designed to operate on very short wavelengths. It will be noted that the overall length of the triode electrodes is only $\frac{1}{2}$ in. Fig. 20 shows the comparative dimensions of the short-wave type and the ordinary tetrode.

The short-wave communication services are so little affected by "atmospherics" that transmitters of comparatively low power and receivers of correspondingly high overall sensitivity are used. Many commercial receivers are regularly used at the limits of sensitivity imposed by inherent valve noise. Development of valve amplifiers has reached a stage at which further increase of sensitivity does not seem profitable, because the noises inherent in valves and their associated circuits determine a lower limit to the input or signal voltage which can be separated from such noise. In the present state of valve development it does not seem likely that much advance can be made in this direction, and therefore high-power transmitters will continue to be required for long-wave services.

Thus, in a short span, the thermionic valve has acquired a complexity and reliability which would have astonished its pioneers. It rests with the younger generation, so many of whom are here to-night, to show that finality has not been reached, so that those here 50 years hence may look upon this decade not as a peak in the history of the valve, but as a gradient in the upward climb to perfection.

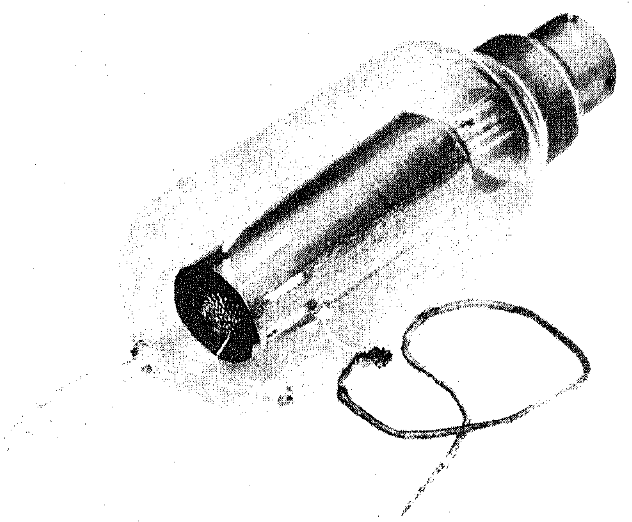

FIG. 7.—Round valve.

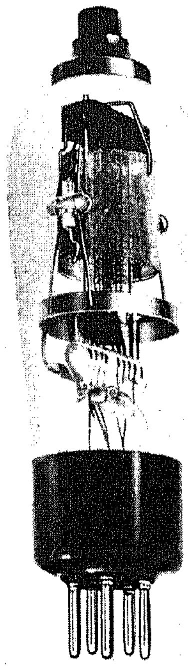

FIG. 8.—Modern screened pentode (1933).

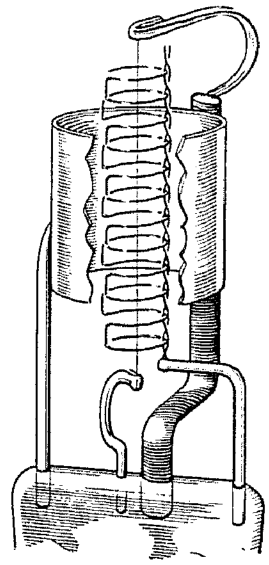

FIG. 9.—An R-valve assembly; practically all handmade.

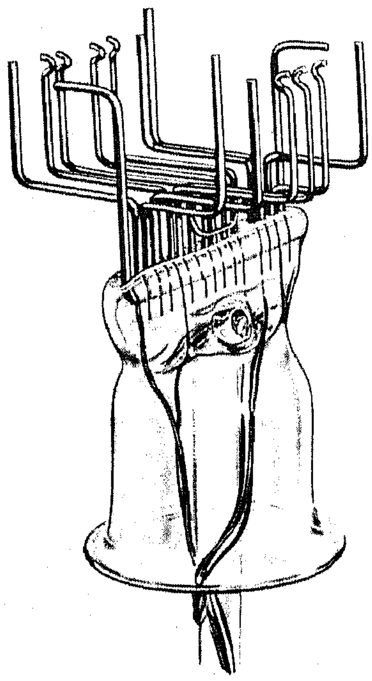

FIG. 10.—Foot of modern battery pentode.

FIG. 11.—Modern grids, delivered continuously from a grid-winding machine.

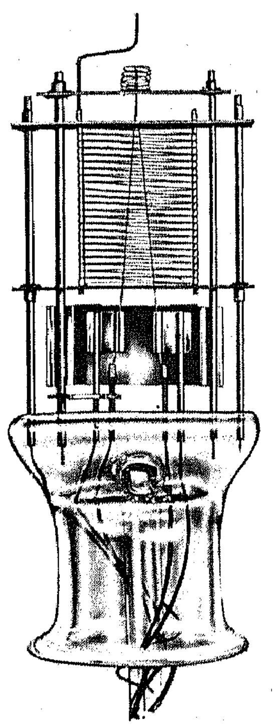

FIG. 12.—Battery double-diode triode, showing filament, grid, and diodes, mounted.

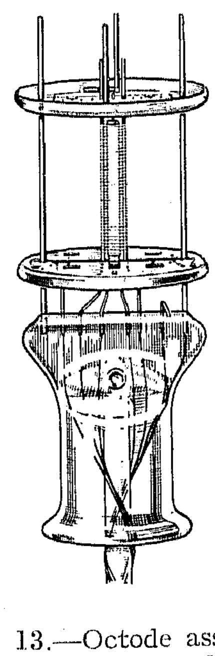

FIG. 13.—Octode assembly, showing cathode, first grid, and distance plates. (Mica insulators are inserted in the distance plates.)

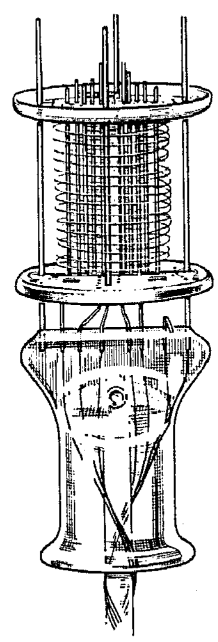

FIG. 14.—Octode assembly with all grids mounted but without anode.

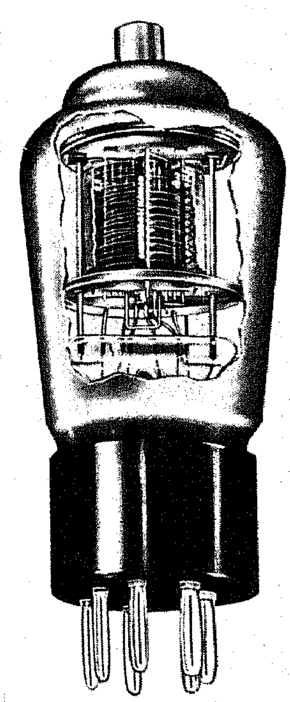

FIG. 15.—Completed octode (glass bulb and anode broken away so as to show all electrodes).

TRANSMISSION SECTION: CHAIRMAN'S ADDRESS

By R. Borlase Matthews, Member.

(*Address delivered* 21*st November*, 1934.)

Summary.

The Address deals with the many problems facing the distribution engineer. To indicate the scope of the work of the Transmission Section the author draws attention to the enormous possibilities of developing the consumption of electricity both in urban and in rural areas. Reference is made to the all-electric home of the future with a consumption of not less than 24 000 units per annum; and the possibilities of rural development with its present power consumption of the equivalent of 2 147 million units. It is shown that rural electrification, when considered on the basis of consumption per mile of conductor, offers a load of over 18 500 units per mile per annum—a figure which compares favourably with that of suburban districts. The immediate work awaiting the attention of the Section is briefly surveyed and particulars are given of a specification prepared by the Overhead Lines Association for standard outdoor transformers suitable for suburban and rural development. The radical changes taking place in agricultural practice are shown to offer unlimited opportunities to the electricity supply undertakings. As an example of what can be done to reduce the cost of overhead lines, particulars are given of an "X"-pole line, costing about £70 per mile, which the author is employing on his estate. Thermal-storage cookers and water heaters, specially suitable for use in rural areas, are described, and the applications of an automatic change-circuit system in conjunction with such apparatus is discussed.

Prospects for Domestic Electrification.

I propose to open this address by presenting two queries to those who reside in houses with, say, not less than eight rooms.

The first query is this: Are there installed in your house 300 to 400 electric lights, and between 50 and 60 electric motors, in addition to a large number of other electric labour-saving and convenience-giving appliances, the whole representing a load of, say, practically 100 h.p.?

The second question is: Is your annual consumption between 18 thousand and 24 thousand units?

At first sight such questions may seem ridiculous in the light of the experience of most people, and to suggest very unusual equipment. They are, however, by no means irrelevant, but, on the contrary, well-considered questions, for there are to-day houses already actually equipped in this fashion. An 8-room (fuel centrally-heated) house in Mansfield was recently fitted out with equipment and appliances which had a total rating of 100 h.p. and a consumption of 18 000 units per annum. A 10-room electrically-heated, but not completely electrically-equipped, house in Glasgow, consumed in the 12 months ending July 1934, 22 941 units; another house, near London, consumed 34 000 units in the same period. There are now quite a number of English houses that consume over 15 000 units per annum.

I recently stayed at a modern luxury hotel. It occurred to me that there seemed to be an extraordinary number of lamps in the bedroom suite: I counted them and found no less than 27, yet all, except five central ornamental lights, had a definite use.

We should remind ourselves that a consumption of 24 000 units per annum at a farthing a unit is only £25: yet consider the labour and expense saved! Few people to-day seem to be able to visualize the extraordinary possible demand and current consumption of a completely electrified home, yet it is not taking much risk to forecast that in another decade the owner of a moderate-size house will require equipment, as a matter of course, up to a standard similar to that already indicated. I have recently collated particulars of such suitable equipment,* and it is extraordinary what a large variety of current-consuming appliances are already available to-day.

To quote Mr. P. J. Pybus, the former Minister of Transport: "No great public service like that of electrical supply can consider its work very far advanced when, out of a total domestic national budget, only one-half of 1 per cent goes to pay for electricity."

So much for domestic prospects; now, turning to rural development, what prospects are there here?

Prospects for Rural Electrification.†

Six years ago some 600 farmers were using electricity, to-day there are over 6 000 such consumers, with a consumption of just over 6 million units; and the number is increasing almost as fast as distribution lines can be extended to them. Still, while this progress is admittedly extraordinarily rapid, it is not even a large number when statistics show that 395 800 farms and holdings in this country are at present using mechanical power of the equivalent of 286 million units (kWh) per annum, plus another 233 million units in the form of animal power, and 142 million units in the farm-houses, totalling 661 million units. These figures are obtained from farm conditions as they are to-day; hence it does not require much imagination to prophesy that as more efficient methods of operating the farms are adopted, not only will more power be utilized but also the standard of living will go up, which will result in a high consumption both in the farmhouse and in the farm-worker's cottage.

The rural population which resides in approximately 280 areas for which rural distribution powers have been

* "Electricity for Everybody" (Electrical Press), 5th ed.

† The statistics in this section have been carefully checked with the official returns of the Ministry of Agriculture and of the Electricity Commissioners, though the interpretation and arrangement are my own.

tance of the farm load.* While there were possibilities of this 10 to 15 years ago, the possibilities to-day are infinitely greater, for during the past few years radical and revolutionary changes have been made in agricultural practice. English agriculturalists cannot profitably farm their land on the lines of prairie farmers: rates, taxes, transport and other costs, are too high. If the agricultural industry is to survive in this country, farming practice must inevitably become more intensive, a greater production being obtained from the same area of land. To do this, however, implies the employment of new methods, more machinery, and more men. The farms in this country cannot any longer be looked upon either as rich men's hobbies or places of drudgery for poor men. They must become businesses, in the best sense of the word.

One of the first developments that we shall probably witness in this country, of farms run on factory lines, is the establishment of hay-drying and disintegrating plants in various parts of the country. An enormous amount of investigational work has already been carried out on this problem in different parts of the world, and during recent years it has assumed much greater importance as a result of the recent experimental work on the nutrient value of young grass and other fodder crops. Drying equipments are now being devised to handle tender grass cut when 3–6 in. high, without destroying the valuable nutrient qualities which such grass possesses. Young grass of this kind, when properly dried, has a food value, weight for weight, practically equal to that of linseed cake. These drying equipments will need electric motors aggregating 150 h.p. In addition to providing highly concentrated foodstuffs, the majority of which are now imported, they have the advantage that the harvesting of the crops, instead of being confined to 2 or 3 weeks in the summer, will be continuous throughout the growing season. For a number of years I have had in successful operation a hay- and crop-curing system as opposed to drying methods, which requires much less current consumption.

With the coming of electric power into rural areas, we shall also see the establishment of small factories for dealing with farm produce, the waste from which will be fed back to the cattle. On the Continent this is now quite a regular practice in conjunction with the manufacture of sugar, potato spirit, beer, etc., while we in this country also have our sugar-beet factories, though not on the farms. The vegetable, fruit, and chicken canning industries are also becoming established. If they are properly organized, particularly as regards distribution, these industries will have a tremendous future.

No apology is necessary for stressing the subject of rural electrification, for in our rural districts there are enormous possibilities, many of which are not even recognized at the moment. Ploughing on the average farm, for instance, would, if done electrically, require more than double the current that is consumed in the whole of the farm buildings. Though electric ploughing has not made much progress in this country, there are in use in other countries ploughing equipments with ratings as large as 250 h.p., while there are many 150-h.p. ploughs in operation. The 80-h.p. combine harvester has been in use in this country for some time. Artificial watering of fields with 30-h.p. turbo-pumps and rain-cannon spraying devices is not a novelty in some parts. Dairies are also becoming more factory-like; for instance, cows are already milked on moving platforms, on lines very similar to those employed in factories for the erection of motor-car chassis and similar mass-production work. Then, again, there is no better indication of the change in outlook that has taken place in the agricultural industry than the careful consideration which is being given to such proposals as unit systems of work and employment on the farm. An example of one of these, concerning which I have carried out a good deal of development and investigation, is the man-helper farm-unit system. The basic principle of this system is first to consider carefully each section of the industry—dairy farming, pig farming, poultry farming, etc.—and then to design special buildings and equip them with the most modern, labour-saving, electrically operated machinery, arranged on lines similar to those followed by the efficiency engineer in a factory. The unit of work is that which can be reasonably accomplished by one man and a helper, working as whole-time specialists, e.g. the care and attention of a definite number of cows, pigs, poultry, etc. Under such a scheme a man and a helper can take care of over 70 cows in milk; or 60 breeding sows and their litters; or 4 000 head of laying hens; and so on. Such specialization would result in better profits for the farmer and also better wages for the worker. The country worker ought to be able to earn the same wage as his urban counterpart; such a scheme as the man-helper unit will bring this about. This man-helper unit scheme, with the coming of an electricity supply in rural areas, could also be applied to many rural industries. In fact, a number of industries at present crowded in towns might well be transferred to far more congenial surroundings in rural districts, to the advantage not only of the proprietors but also of the employees. Central selling and distribution centres would, of course, have to be established. The system is a true back-to-the-land movement, whereby the workers would also be able to grow their own vegetable and fruit crops, and it is all brought within the bounds of possibility through the aid of electric transmission and distribution.

Extra-High-Tension Transmission.

It has been my good fortune to be associated with the designs of about 400 lines intended to operate at more than 50 000 volts, including one each of 300 000 and 400 000 volts respectively, for emergency use; and also with one (never constructed) of 700 000 volts. Some of this work was described in a paper* by Mr. C. T. Wilkinson and myself which was read before the Institution in 1911. This has all afforded a very interesting experience, both mechanical and electrical. As fast as one difficulty is solved, another seems to arise. Hence the subject is ever new and interesting.

At the moment the threshold is opening for direct-current transmission by means of valves at voltages that are much higher than anything contemplated

*Journal I.E.E., 1922, vol. 60, p. 725; 1926, vol. 64, p. 801; and 1928, vol. 66, p. 1180.

* Journal I.E.E., 1911, vol. 46, p. 562.

this load, but it will most certainly be its business to see that the current is distributed and supplied, and by the most economical means.

The work of the Section will be to deal with all matters relating to the study, design, manufacture, construction, maintenance, and operation, of overhead and underground power transmission and distribution lines and cables, i.e. of lines and cables for all purposes other than those of electrical communication. Undoubtedly the Section will prove one of the most important in the Institution. Nearly 2 000 applications for membership have already been received; it is obvious that not all of these applications can be accepted, owing to lack of sufficient experience on the part of some of the applicants. The object of the Section is, of course, to bring together all classes of members of the Institution who are actively engaged in, or are teaching in, one or other of those branches of the profession which come within the scope of the Section. All classes of members of the Institution, however, will be welcome at our meetings and may participate in the discussions and also invite their friends as visitors. It will be fully appreciated, therefore, that while membership of the Section may be closely restricted to those who have the necessary professional qualifications, its meetings will be open to all who are in any way interested or who can add to our store of knowledge.

In the present stage of development of our industry one of the real problems is efficient distribution. Generation problems have become more or less stationary and it is not easy to visualize an appreciable lowering of the cost of generation, but the present cost of distribution is still much too high. Transmission problems are practically non-existent in this country, as the grid is really only a set of busbars. Hence the real work of this Section deals with distribution from the grid to the meter-board of the consumer.

Programme of the Transmission Section.

The Overhead Lines Association, which was the forerunner of the Section, paid special attention, among all the other matters that came within its scope, to wayleaves, standardization of wayleave agreement forms, the Overhead Line Regulations, amendments to the Overhead Line Regulations, and rural-transformer specifications. A great deal of painstaking work has been done on these subjects, but much still remains to be done. In addition there is much other work which this Section can accomplish. It is for this reason that I trust that every member of the Institution who is qualified to do so will make immediate application for membership of the Section. One of the most valuable aspects of a body such as ours is that it affords an opportunity for those interested to exchange information, whereby the experience of each one of us may be pooled for mutual benefit. A single, united Section of our parent Institution can deal with all necessary matters in a far more efficient and satisfactory manner than is possible by separate and individual working.

There is still a very big field for research in connection with surge problems. Though lightning is not as troublesome in this country as elsewhere, the problem of dealing with its vagaries still requires further investigation. Protective devices of an electrical nature, designed to cut off the current when a line breaks, are yet in their infancy. One of the difficulties that requires immediate attention is the prevention of the breakage of overhead lines due to the vibration of the conductors. There are also the inductive effects which arise on the breakage of a line and which may under certain conditions influence communication wires many hundreds of yards away.

Further development in insulator design is needed along the lines so ably expounded by the President in his recent Inaugural Address.*

A British Standard Specification for ferro-concrete poles is already in draft form and should be of great assistance to those who are contemplating the use of this class of support, which modern conditions indicate to be desirable. Very little work has been done in this country on ferro-concrete foot mountings for wooden poles. They should do much to reduce costs and facilitate replacements. After all, following the practice of the communications engineer, the power distribution engineer has employed impregnated poles to a very considerable extent. The cost of impregnation could be reduced, and also cheaper, shorter poles could be employed with the aid of footings. Over a million of these footings are in use in France alone, and they are employed on a similar scale in other countries.

The employment of carrier currents on power lines, for radio, telephone, and signalling work is still in its early stages. The day may yet come when we shall see more joint use of poles for power and communication purposes, thus reducing the number of poles necessary for all purposes. Many pole-line designers in this country weaken their poles at vital points by too much drilling, and they also increase their labour costs by doing too much of the work on the roadside. As much work as possible should be carried out in a factory. There is ample scope for the design of fittings which clamp securely on poles.

The ideal railway and road crossing does not seem yet to have been arrived at, so this matter must have further attention. There are also still many unsolved problems as regards cables—their manufacture, laying, operation, and maintenance.

Electricity Regulations.

Past experience has shown that the Electricity Commissioners often adopt a broader point of view as regards rules and regulations than do many of the electricity supply undertakings of this country. In fact, if the electricity supply industry had been more of one mind the Commissioners would undoubtedly have granted even further concessions. Time and time again the Commissioners have granted special relaxations from their rules—as it is in their power to do—to those engineers who are thoroughly competent. On the other hand the Commissioners are charged with the duties of the Board of Trade, as regards the safety of the public, and they do not have to bear the additional cost of the lines brought about by any regulations they may issue. After all, the interests of the public are best served by reasonable safety with low cost of distribution. Some detail points that require careful examination are the effective-

* See page 1.

ness of earthing bars at road crossings as ordinarily fixed to poles, in the event of a line breaking. [This is called for in Regulation No. 18(2), El. C. 53 (revised).] Then there is the much-discussed question as regards the bonding of insulator pins and metal-work [as specified by Regulation 14(2) (*b*) (i)]. The question also arises as to whether it is advisable under any special circumstances to employ bakelized or other treated wooden pins and generally eliminate metal-work. Earthing rules are another factor that requires further looking into. Again, there is the effect of geographical position on line construction regulations. Is the mechanical strength assumed for copper too low, and is too high a value placed upon the modulus of elasticity? These are two questions that require more investigation.

Electricity Bills.

Among other duties that may fall to the lot of this Section is the consideration of any Electricity Bill that may come before Parliament—of course from a technical and not from a political point of view. It will have been noted from the King's Speech that an Electricity Supply Bill is foreshadowed for the coming sitting of Parliament. Further, it is likely that a Distribution and Sales of Electricity Bill may come forward in the near future, should the majority of the existing electricity supply undertakings not develop their educational publicity work more rapidly than at present.

A Rural-Transformer Specification.

As one illustration of the work of the Overhead Lines Association I have been requested to bring before your notice a specification which was prepared for standard outdoor transformers suitable for outer suburbs and rural development, in the hope that you will amend, improve, and give it your authority. A copy of this specification will be sent in the near future to every member of this Section, for this purpose. The object of the specification was to take up the matter where B.S.S. No. 171 stops, with a view to bridging the gap between the maker and the user, for the benefit of both. The maker finds a difficulty in many cases in choosing the design to suit the often unspecified conditions. On the other hand the user is often unable to choose wisely between the offers he receives, because they vary so much in regulation losses and the kinds of fittings offered, as well as in the prices. The specification is designed to apply only to the working conditions as to voltage, load factor, outdoor location, size, tappings, etc., to comply with the average conditions met with in outer suburban and rural development in this country.

Turning now to the main points of the specification, it may be mentioned that, as 230 volts is the standard a.c. consumer's voltage, this was selected as the transformer standard. The number of sizes was reduced to 5 and 10 kVA for single-phase and to 25, 50, and 100 kVA for single-phase and 3-phase. The temperature-rises were arrived at by the testing of actual rural transformers in use by means of recording thermometers. As regards regulation, for unity power factor an average of 2 per cent was prescribed (actually $2\frac{1}{2}$ for 5-kVA and $1\frac{3}{4}$ and $1\frac{1}{2}$ respectively for 50- and 100-kVA sizes). The tappings are arranged as one $2\frac{1}{2}$ per cent step above normal high voltage and three similar steps below, all at no load. Externally-operated tap switches are called for on transformers of 50 kVA and over. Lifting eyes or lugs are to be welded on to the tanks. The terminals are to be all of one size, length, etc., for all sizes of transformers. Fixing hooks are to be arranged to fit 2-in. channel iron. A diagram of connections is to be attached. Earthing terminals are to be fitted, as well as combined oil emptying and sampling plugs. The tanks are to be provided with smooth bottoms or with shaped channels, so as not to dig into the ground.

Having standardized transformers, the question arises whether it would not be advantageous for us to standardize other features of overhead-line construction.

Rural Electrification.

While the scope of the Section's work will cover all branches of the transmission and distribution industry, there is one branch in particular which should benefit greatly by its work, i.e. rural electrification. There is still a good deal of doubt in the minds of many engineers as to the wisdom of developing rural areas. I venture to say, however, that these areas, if properly developed, will during the course of the next few years provide the central-station engineer with as remunerative a load per mile of the distribution system as that now being obtained in urban areas. It is true that the technique of development will not be the same as that for urban areas, and it is in this respect that there still exists much misunderstanding.

Taking the country as a whole, it is suggested that it should prove remunerative at the present time to provide a supply to from 60 to 70 per cent of the rural areas. The remaining portions, owing to the unfertile nature of the soil and the low density of population, will undoubtedly have to be left for some years.

The first question of importance in developing a rural area is to decide upon the minimum size which will carry the necessary overhead charges. As a general rule, such an area should have a population of at least 120 000 to justify its development as a separate undertaking. To endeavour to electrify a small rural area apart from the general scheme, not only entails waste of capital, but also makes the electrification of surrounding districts far more expensive, if not impossible. Development in the large areas should also be laid out so that it proceeds systematically from district to district, each district from the beginning forming part of the one large scheme.

An examination of some rural schemes in operation to-day shows that by far the largest proportion of consumers is domestic and that the bulk of the current sold is taken by factories, works, etc., on the outskirts of towns. This seems to indicate that those in charge of the schemes have been primarily concerned with the industrial and residential possibilities of the area; the farm load, if any, obtained being a secondary consideration. This is unfortunate, for if the greatest possible rural development is to be attained, due regard must be paid to the individual load from farms and villages, etc. For some years past I have stressed the impor-

tance of the farm load.* While there were possibilities of this 10 to 15 years ago, the possibilities to-day are infinitely greater, for during the past few years radical and revolutionary changes have been made in agricultural practice. English agriculturalists cannot profitably farm their land on the lines of prairie farmers: rates, taxes, transport and other costs, are too high. If the agricultural industry is to survive in this country, farming practice must inevitably become more intensive, a greater production being obtained from the same area of land. To do this, however, implies the employment of new methods, more machinery, and more men. The farms in this country cannot any longer be looked upon either as rich men's hobbies or places of drudgery for poor men. They must become businesses, in the best sense of the word.

One of the first developments that we shall probably witness in this country, of farms run on factory lines, is the establishment of hay-drying and disintegrating plants in various parts of the country. An enormous amount of investigational work has already been carried out on this problem in different parts of the world, and during recent years it has assumed much greater importance as a result of the recent experimental work on the nutrient value of young grass and other fodder crops. Drying equipments are now being devised to handle tender grass cut when 3–6 in. high, without destroying the valuable nutrient qualities which such grass possesses. Young grass of this kind, when properly dried, has a food value, weight for weight, practically equal to that of linseed cake. These drying equipments will need electric motors aggregating 150 h.p. In addition to providing highly concentrated foodstuffs, the majority of which are now imported, they have the advantage that the harvesting of the crops, instead of being confined to 2 or 3 weeks in the summer, will be continuous throughout the growing season. For a number of years I have had in successful operation a hay- and crop-curing system as opposed to drying methods, which requires much less current consumption.

With the coming of electric power into rural areas, we shall also see the establishment of small factories for dealing with farm produce, the waste from which will be fed back to the cattle. On the Continent this is now quite a regular practice in conjunction with the manufacture of sugar, potato spirit, beer, etc., while we in this country also have our sugar-beet factories, though not on the farms. The vegetable, fruit, and chicken canning industries are also becoming established. If they are properly organized, particularly as regards distribution, these industries will have a tremendous future.

No apology is necessary for stressing the subject of rural electrification, for in our rural districts there are enormous possibilities, many of which are not even recognized at the moment. Ploughing on the average farm, for instance, would, if done electrically, require more than double the current that is consumed in the whole of the farm buildings. Though electric ploughing has not made much progress in this country, there are in use in other countries ploughing equipments with ratings as large as 250 h.p., while there are many 150-h.p. ploughs in operation. The 80-h.p. combine harvester has been in use in this country for some time. Artificial watering of fields with 30-h.p. turbo-pumps and rain-cannon spraying devices is not a novelty in some parts. Dairies are also becoming more factory-like; for instance, cows are already milked on moving platforms, on lines very similar to those employed in factories for the erection of motor-car chassis and similar mass-production work. Then, again, there is no better indication of the change in outlook that has taken place in the agricultural industry than the careful consideration which is being given to such proposals as unit systems of work and employment on the farm. An example of one of these, concerning which I have carried out a good deal of development and investigation, is the man-helper farm-unit system. The basic principle of this system is first to consider carefully each section of the industry—dairy farming, pig farming, poultry farming, etc.—and then to design special buildings and equip them with the most modern, labour-saving, electrically operated machinery, arranged on lines similar to those followed by the efficiency engineer in a factory. The unit of work is that which can be reasonably accomplished by one man and a helper, working as whole-time specialists, e.g. the care and attention of a definite number of cows, pigs, poultry, etc. Under such a scheme a man and a helper can take care of over 70 cows in milk; or 60 breeding sows and their litters; or 4 000 head of laying hens; and so on. Such specialization would result in better profits for the farmer and also better wages for the worker. The country worker ought to be able to earn the same wage as his urban counterpart; such a scheme as the man-helper unit will bring this about. This man-helper unit scheme, with the coming of an electricity supply in rural areas, could also be applied to many rural industries. In fact, a number of industries at present crowded in towns might well be transferred to far more congenial surroundings in rural districts, to the advantage not only of the proprietors but also of the employees. Central selling and distribution centres would, of course, have to be established. The system is a true back-to-the-land movement, whereby the workers would also be able to grow their own vegetable and fruit crops, and it is all brought within the bounds of possibility through the aid of electric transmission and distribution.

Extra-High-Tension Transmission.

It has been my good fortune to be associated with the designs of about 400 lines intended to operate at more than 50 000 volts, including one each of 300 000 and 400 000 volts respectively, for emergency use; and also with one (never constructed) of 700 000 volts. Some of this work was described in a paper* by Mr. C. T. Wilkinson and myself which was read before the Institution in 1911. This has all afforded a very interesting experience, both mechanical and electrical. As fast as one difficulty is solved, another seems to arise. Hence the subject is ever new and interesting.

At the moment the threshold is opening for direct-current transmission by means of valves at voltages that are much higher than anything contemplated

*Journal I.E.E., 1922, vol. 60, p. 725; 1926, vol. 64, p. 801; and 1928, vol. 66, p. 1180.

* *Journal I.E.E.*, 1911, vol. 46, p. 562.

before. While no commercial line has yet been constructed, the laboratory and experimental work has been completed, and hence it is only a question of getting some bold spirit to place an order. This method will undoubtedly give rise to a new set of problems, and will enormously reduce the cost of transmission and distribution.

Cheap Overhead Lines.

As a demonstration of what can be done to reduce the cost of overhead lines, reference may be made to a type of pole which I am now employing on my all-electric farm (see Figs. 1–4). The general principle of the design is the accepted one of employing stout anchor posts at ¼-mile intervals, with intermediate supports which are flexible* in the direction of the line and very rigid sideways. The novelty lies in the substitution of sawn timber in place of the natural tree trunk normally employed, and the avoidance of the wind and weather line, since no wood enters the ground. The intermediate supports are constructed of two 22-ft. (or longer) sawn lengths of 4-in. × 2-in. (cross-section) unimpregnated fir. They are painted with creosote before erection. They are bolted together just above the centres with a ½-in. timber bolt, to form a cross or X-shaped frame, and are tied together at the top with another short timber cross-brace of the same section. The complete structure is hinged by single bolts on to two 2-ft. lengths of galvanized iron piping, set in waterproof footings which are constructed of small reinforced-concrete blocks. The total weight of the pole is well under 75 lb. The cross-member, while forming a tie to the framework, also acts as a spacer for the insulators. These are of the pin type and are screwed into the ends of the upper arms of the frame. The iron piping is pre-cast into the concrete blocks, which are each of about 1 cub. ft. and are lined up into position ready to take the frame. Where the direction of the line varies slightly the frames are stiffened by a vertical piece of timber, which carries the side pull to the foundation block. On sharper bends a third block is introduced, thus making the frame self-supporting. Should it be necessary to mount a transformer on the pole an additional cross-brace can be fitted and the transformer hung on one side of the centre of the cross-brace, so that its weight helps to

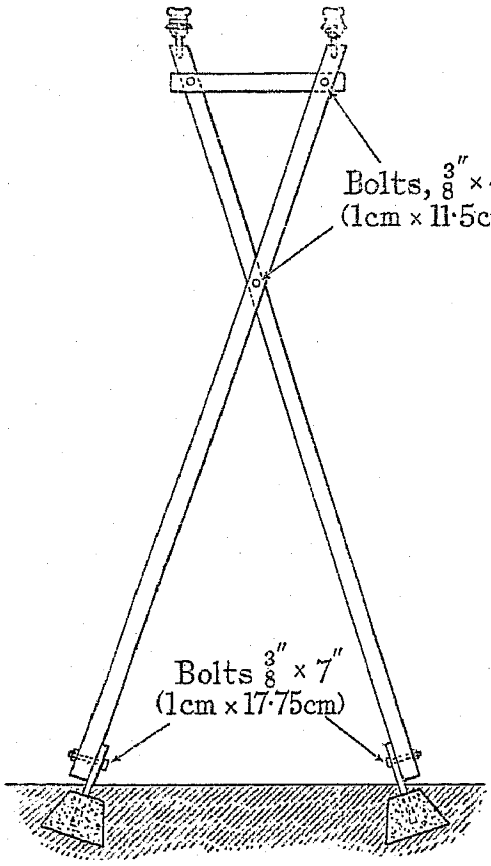

Fig. 1.—Intermediate "X" pole.

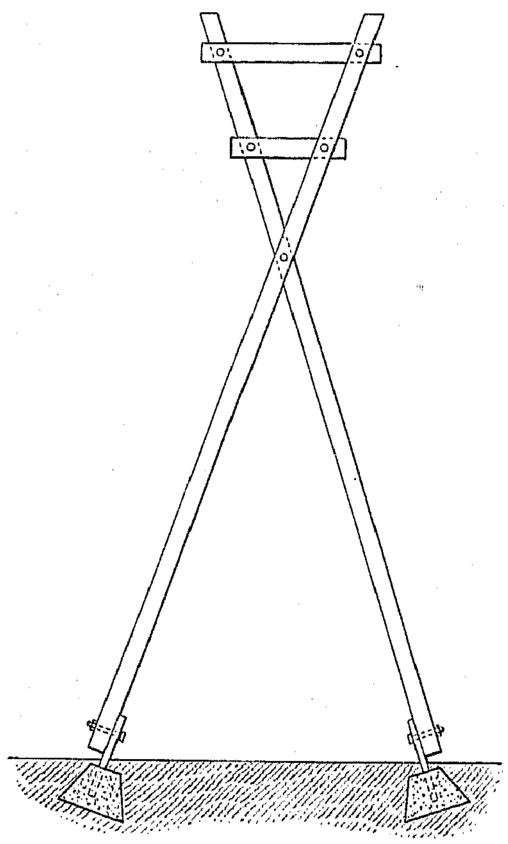

Fig. 2.—"X" pole for transformer and service line.

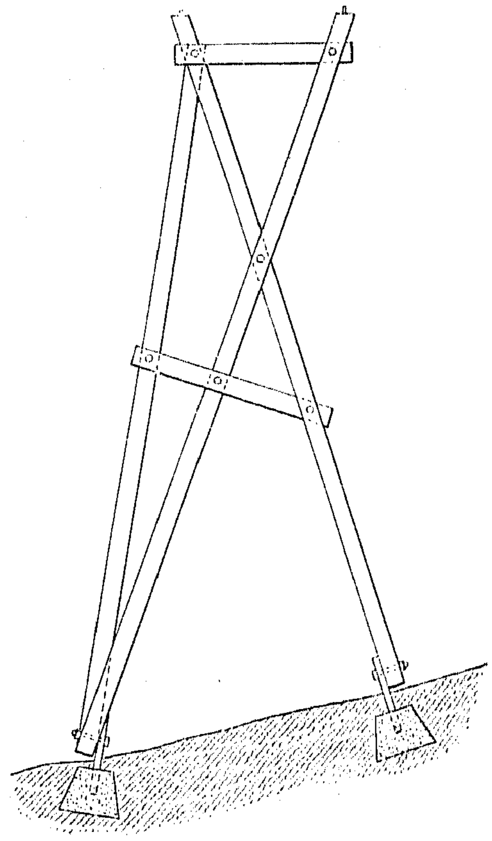

Fig. 3.—"X" pole on hillside, and bracing for curve in line.

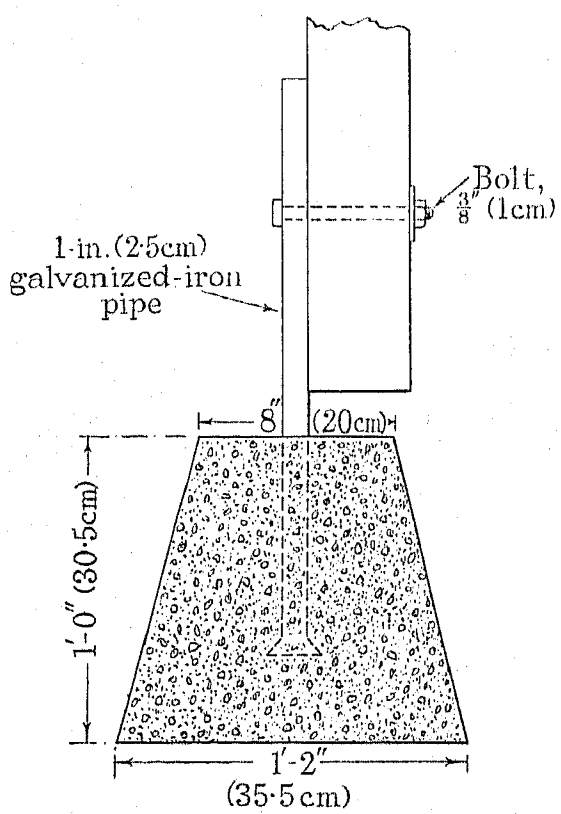

Fig. 4.—Concrete footing block for "X" pole.

* R. Borlase Matthews and C. T. Wilkinson: *loc. cit.*

balance the pull of the service wires. The anchor frames are placed at intervals of $\frac{1}{4}$ mile, at road or line crossings, at transformer points, and where the lines change direction. These are of stronger construction and may be either ordinary poles or 3-in. × 4-in. sawn timber.

A single-phase rural line of this type can be erected at a cost of £70 per mile. It will be seen that there is an enormous saving as compared with ordinary poles, for, notwithstanding the expense of sawing the timber, the cubic content of wood is much less, the transport costs are reduced since the weight to be transported is less, a man and a boy only are required to handle the pole, and sawn timber can be packed in a much smaller space than ordinary wooden poles. Further, sawn timber is a commercial article obtainable almost anywhere.

While the design may not meet with the approval of all overhead-line engineers (it certainly takes up more ground space than the usual pole), it demonstrates that there are other methods than the orthodox ones for the construction of overhead lines. This " X " pole design should at least provide food for thought for all overhead-line engineers.

Mid-Lincolnshire Electrification Scheme.*

This scheme provides an excellent example of modern rural development. It is the largest Provisional Order ever granted by the Electricity Commissioners. It covers an area of 1 636 square miles, which represents 3·2 per cent (or $\frac{1}{33}$) of the total area of England (see Fig. 5). The scheme comes within the Mid-East England area of the Central Electricity Board, and supplies are taken from the Board at nine different points.

The first sections of the 33 000- and 11 000-volt lines for this scheme were erected at a cost of £500 and £380 per mile respectively. The 33 000-volt line is of the suspended-insulator type; it is very strongly built, as it is not intended to duplicate it and it also has to withstand salt-spray storms direct from the North Sea.

Rutter pole construction has been adopted for some of the 33 000-volt lines. The conductors are of cadmium-copper and the normal span is 520 ft. These lines present new and interesting constructional features. Firstly, tension clamps for a 3-strand conductor of this hard material presented some difficulties. The ordinary bolted clamp was considered unsuitable on account of its weight, being likely to cause vibration-fatigue and breakage of the conductor where it leaves the clamp, and the lighter cone-type clamp was scarcely practicable with a 3-strand conductor. Therefore a new method of making-off was devised, and on test it gave such consistently satisfactory results that it was adopted. The make-off consists in passing the three wires, untwisted and placed side by side, over a thimble; and then, after twisting the ends into the interstices in the main cable, affixing three single clamps at 4-in. intervals. At 8 in. from the first clamp the wire is cut and the end bound in with No. 14 S.W.G. soft copper wire. The second and third wires are carried a further 8 and 16 in. respectively, and then similarly bound. Owing to the lightness of this method, a gradual damping effect is obtained.

* I am indebted to Mr. C. E. Maguire and Mr. L. Giacomuzzi (engineer and general manager respectively for the carrying out of the scheme) for some of the particulars given in this section of the address.

The second point of interest is the protection provided against atmospheric disturbances. Much of the ground along the route is low-lying, damp, and eminently suitable for individual earth plates at each pole. It was therefore decided that the additional cost of a continuous earth wire, with the stronger poles which would have been necessary, was not warranted. Instead, a protection of greater value than a continuous earth wire was adopted. Projecting some 12 in. above the top of each pole is a wrought-iron spike pointed sharply like a centre-punch, and galvanized. This is connected to the earth plate by means of an earth wire, which also serves to earth the cross-arms. The principle of this form of protection is exactly the same as that of the so-called lightning conductor on a factory chimney, and is intended to prevent, by brush discharge, the building-up of high potentials

Fig. 5.

between the earth and clouds in the neighbourhood of the line.

Though the Mid-Lincolnshire scheme has only been in operation a little over 2 years, it is estimated that there are over 6 000 consumers connected to the supply mains. Up to the end of 1933 practically £200 000 had been invested in the area.

Thermal Storage.

This is a subject that is closely bound up with distribution. Its consideration requires a different economic comprehension and conception from that applied to the ordinary load and diversity-factor problems. Further, it does not seem to be readily understood by those who have not made a careful, detailed study of it.

I obtained my first practical experience with thermal-storage cookers in pre-War days. In connection with a recent scheme for the rural development of Mid-Lincolnshire, the designs have been further advanced. An example of a thermal-storage cooker which was evolved from a specification drawn up by me is shown

in Fig. 6. It is worthy of note, as a trend of modern progress, that the cooker, both in its original and in its present revised stage, was created by the research department of an electrical manufacturer and not merely by a designer in a drawing office, who naturally has no experimental facilities to assist him. This particular cooker is of special interest as it has no thermostat, surplus heat being dissipated by radiation. Also it has no switch for turning it on and off; it is always ready for use. Its performance eclipses that of any competing apparatus of more conventional principles, whether electrically-heated or fuel-heated, for it will raise the temperature of 3 pints ($3\frac{3}{4}$ lb.) of water from

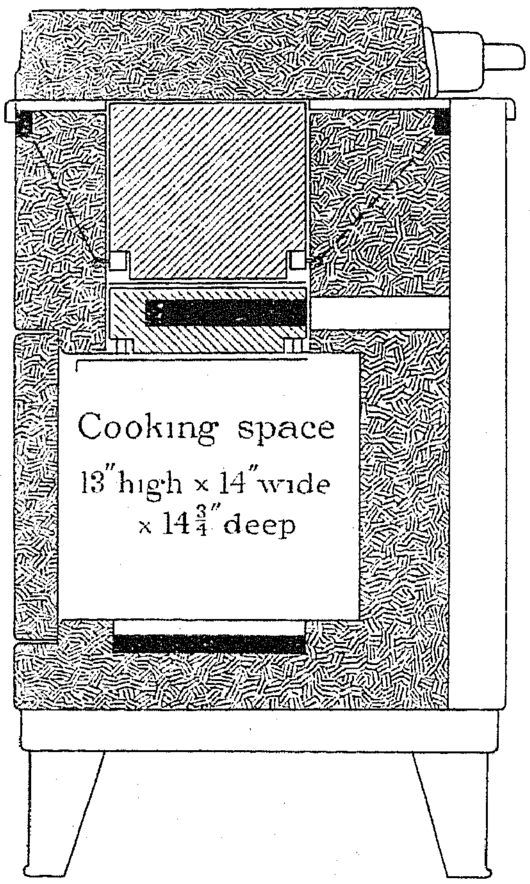

FIG. 6.—An electric thermal-storage cooker with heating block divided into two portions.

15° to 100° C. in $1\frac{1}{2}$ minutes with an initial block temperature of 550° C. (early-morning conditions), or in 2 minutes with a block temperature of 450° C. Even after a midday dinner has been cooked, when the temperature of the block has been reduced to 200° C., the same operation only takes 8 minutes. There is a diverting switch, so arranged that current can be diverted when required from the block, to add to the oven additional heat to that obtainable from the store in the block. A recent very important improvement on the part of the manufacturers has been to divide the block into two portions. This is for the reason that the quantity of heat that can be stored in a cast-iron block is proportional to the product of its mass and its temperature. The upper block, weighing 165 lb., is arranged for the lower-temperature task of boiling and stewing; while the lower, weighing 60 lb., is arranged for the higher-temperature work of heating the oven. An air-gap is arranged between the two blocks so that the flow of heat between them may be restricted to the extent of maintaining a temperature-difference of about 80 deg. C. By virtue of the thermal resistance of this gap the rapid withdrawal of heat from one block has very little effect on the other. The lower-block loading is 450 watts, with a diversion to 500 watts (an increase of 11 per cent) in the oven, giving a load factor of just over 90 per cent.

With the longer sub-distribution lines in rural areas 100 per cent thermal storage is of advantage, but in more densely populated areas this matter is open to discussion. Here, however, the cooker problem can be more effectively met by a 2-kW maximum-demand semi-storage apparatus than by the normal 6- to 8-kW conventional 6-person cooker. A semi-storage cooker is shown in Fig. 7. The hot-plate block is of the thermal storage-type, but the oven and oven-grill are

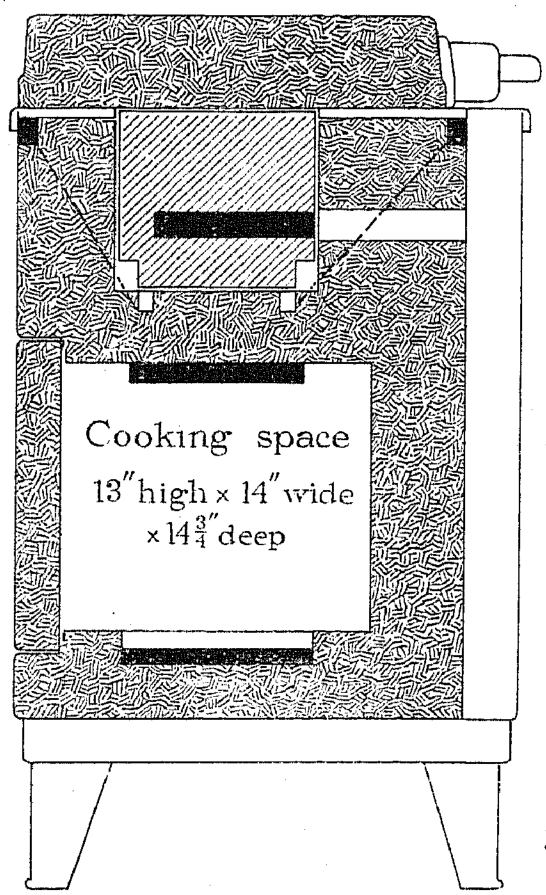

FIG. 7.—A semi-thermal storage cooker.

heated in the more usual manner. The block contains two 250-watt heating elements (arranged for 125, 250, and 500 watts switching); the grill, 1 500 watts in two 750-watt elements; and the oven bottom, two 600-watt elements ("high," 1 950 watts, "low," 600 watts). Owing to the diverting-switch control the total power that can be put on at one time is 1 950 watts.

A water heater may be run in conjunction with this latter type of cooker, so switched that it cannot be in circuit when the oven or grill loadings are in use.

More particularly in rural work, the difficulty often arises, when thermal-storage water heaters are being introduced, of no existing main supply of water. Again, where such a supply does exist, the plumbing work in connection with the installation often amounts to a very appreciable proportion of the total cost. Further, the rural consumer is often not in such a strong financial position as the urban ones, and therefore cannot afford to purchase or hire the type of water heater now on the market. To meet these various difficulties in connection with the Mid-Lincolnshire electrification scheme, I designed

a thermal-storage water heater (see Fig. 8) which can be built at about half the cost of the average heater of this class and does not need any plumbing work to install it. It is of the displacement type, with no joints below the normal water-level. A bucketful, or any other required quantity of water, can be poured into it—once it has reached its full normal temperature—and immediately an equivalent quantity of hot water is displaced. To the ordinary householder this process almost savours of a conjuring trick. If a water supply from tanks or

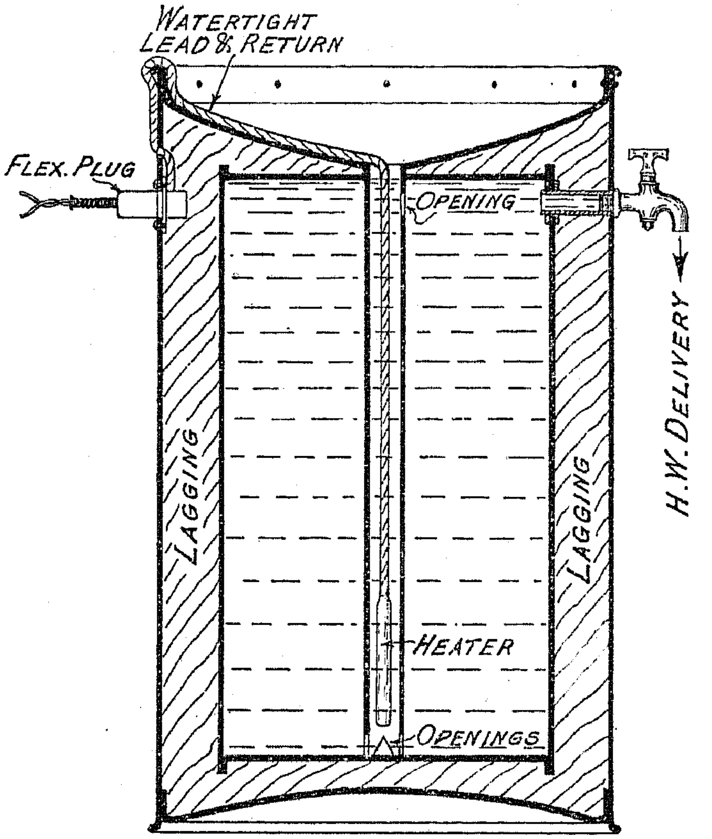

FIG. 8.—A thermal-storage displacement-type water heater needing no plumbing or installation.

mains is available, the tap or a rubber hose-pipe can be brought over the top of the water heater for the supply of the cold water which is to displace that already heated. The outlet tap can also be removed and the heater connected to a distributing piping system, if desired. The rating is 300 watts, and the total capacity is 18 gallons. This heater in its standard form is capable of delivering 10 gallons of very hot water per day, and of maintaining its normal maximum temperature. The extra capacity permits of the use of more than 10 gallons on one day, quite hot enough for a bath or for general use, provided the user will put up with a little less the next day. The daily output can, of course, easily be increased, if desired, by increasing the rating of the heater. The general design is such that any repairs can be carried out without emptying the container. Incidentally the heat insulation material with which the inner tank is surrounded is found as a natural deposit on the farm where these heaters are at present being constructed—virtually a new rural industry.

There is a big opening also for the thermal-storage heating of rooms.

The above examples indicate that suitable apparatus is already available for those who wish to take advantage of 100 per cent load factor in their distribution schemes. A further feature of the introduction of the thermal-storage principle is that the consumer is not seriously inconvenienced by the temporary cutting-off of current.

Owing to the fact that thermal-storage apparatus is now available, an automatic change-circuit system operated by a special form of induction regulator can be applied. This very greatly improves the load factor, bringing it up very nearly to unity. With thermal-storage apparatus, the voltage of supply is really unimportant, for it is the product of the volts and the amperes, i.e. the watts, that determines the heat energy available to the consumer. The change-circuit system can be applied to any existing distribution system by the addition of a suitable induction regulator and the provision of an extra feeder per phase. Like many new lines of thought, the general principles of an induction-regulator change-circuit system are a little difficult to grasp at first. The whole matter is, however, well worthy of time, attention, and adoption, in view of the method of charging adopted under the grid scheme. In itself it makes a most interesting distribution problem. It is particularly adaptable to new building estates and blocks of residential flats. It is certainly a serious attempt to increase the off-peak load. It almost entirely eliminates the defects of time-switch and limiting-device systems, and yet retains their advantageous features.

CONCLUSION.

The scope of the Transmission Section is obviously very extensive, and the art of the transmission and distribution engineer is evidently still far from finality, for, as has been indicated in this address, many difficulties still have to be overcome and, in particular, distribution costs have yet to be very considerably reduced. Hence we have a very interesting field set out before us, with a long furrow to plough, if we are to accomplish what is a matter of great national importance. Only in this way can the now electrically-minded public obtain that full distribution of electricity for which they are calling.

MERSEY AND NORTH WALES (LIVERPOOL) CENTRE: CHAIRMAN'S ADDRESS

By R. G. Devey, Member.

"ELECTRICITY IN INDUSTRY."

(Abstract *of Address delivered at* Liverpool, 15*th October*, 1934.)

Introduction.

In this address I intend to deal with the problem of electricity with special reference to industry, outlining the means of obtaining electricity and some of the more important phases in connection with its use in factories.

At the outset it will be of general interest to refer to the statistics set out in Tables 1 to 4, which give some idea of the importance of industrial electricity.

Table 1.

Occupational Distribution of Population.

Occupation	Great Britain (1931)	United States (1930)	Germany (1925)	France (1926)
	per cent	per cent	per cent	per cent
Manufacturing industries, commerce, and transportation	74·8	56·2	57·8	50·4
Agriculture, forestry, and fishing ..	6·6	22·0	30·5	38·3
Other occupations ..	18·6	21·8	11·7	11·3

Table 2.

Sales of Electricity by Authorized Undertakers in Great Britain, for the year 1931–32 (*Latest Available Figures*).

	million kWh
Public lighting ..	183
Traction	811
Domestic	3 071
Industrial power ..	5 435

Electrical Power for Factory Use.

The following are the usual means of obtaining electricity: (*a*) independent steam, oil, or gas generating plants, operating as complete generating units; or (*b*) by utilizing steam supplied from factory boiler-plant, such plant being common to power and process steam; or (*c*) generation as a by-product by steam plant, usually turbines, of which there are four main types, namely back-pressure, pass-out, mixed-pressure, and exhaust, these being variously employed according to the process demand or steam surplus of the industry under consideration; or (*d*) by purchase from an outside source.

In large factories electricity is generated in almost every case from steam; in small factories the prime movers may be oil or gas engines; but each type has been influenced by local conditions, and in some cases coal, water, and electricity, are not easily available.

The question of taking power from an outside source calls for careful consideration, and when investigated it should then be possible to decide whether it is better to purchase power from an outside source or to generate it direct in the factory. In some cases the examination of figures and industrial characteristics is not sufficiently thorough; this point will be dealt with later.

Table 3.*

Mechanical and Electrical Power Available in Certain Industries which Employed Approximately Two-Thirds of the Total Horse-Power.

	1907	1924	1930
	Thousand h.p.	Thousand h.p.	Thousand h.p.
Electrical	934·7	5 095·1	7 457·5
Reciprocating engines	4 220·2	3 892·3	3 143·7
Other types ..	556·2	517·9	698·0
Total	5 711·1	9 505·3	11 299·2

* The 1907 census included Great Britain and Ireland. The 1924 and 1930 figures do not include the Irish Free State.

Table 4.*

Percentages of Mechanical and Electrical Power in Industry.

	1907	1924	1930
Electrical	16·4	54·6	66·0
Mechanical ..	83·6	46·4	34·0

* The 1907 census included Great Britain and Ireland. The 1924 and 1930 figures do not include the Irish Free State.

Electricity to-day can be purchased from an outside source at low prices to such an extent that many factories are now going over to public supply. In addition, such a course provides a means of cutting out mechanical power losses due to heavy shafting, gears, belt drives, etc., as, with the old-fashioned steam-drive, the whole

of the power is transmitted mechanically from the steam engine to the farthest point of the machinery to be driven.

The steam engine may also be used in the individual driving of machines, but this method has little application in a modern factory, except in such cases as will be referred to at a later stage.

Electricity Generated as a By-Product.

Where a factory uses both electricity and process steam, an investigation is called for as to the possibility of obtaining electric power as a by-product.

As previously indicated, there are four main types of plant (see Fig. 1) which may be used in factories of this kind to ensure the economical use of steam. Briefly, these are:—

(i) *Back-Pressure Plant.*

This plant may be of the turbine or of the reciprocating-engine type; usually the former is employed, the reciprocating engine being mainly used for the lower-capacity plants. The back-pressure plant may only be used where one of the following two conditions exist, in each case the turbine being supplied at high pressure and the process steam being required at relatively low pressure: (*a*) where the demands for electricity and process steam are in direct proportion and have identical load curves; (*b*) where the steam demand is always in excess of that which may be supplied by the generating set, in which case the balance of the steam may be made up through an automatic reducing valve, and de-superheating apparatus employed where required.

Various modifications may be introduced by the multiplication of generating sets and different primary steam pressures.

(ii) *Pass-Out Plant.*

More flexibility is obtained with a pass-out plant, but this is more costly to install owing to the necessity for a condensing plant and the essential auxiliaries, which are usually designed to deal with the weight of steam required to develop 70–80 per cent of the full load. An added advantage of the pass-out type of plant is that process steam can be bled from the turbine at practically any desired pressure between the stop-valve pressure and the vacuum obtaining in the condenser.

(iii) *Mixed-Pressure Plant.*

Where the reverse of the conditions for back-pressure turbines is the case—i.e. where there are quantities of low-pressure steam available, with higher pressure when required—the mixed-pressure plant is used. The source of the low-pressure steam may be process work or any reciprocating engines previously exhausting to atmosphere; and, according to fluctuation of the electrical load and low-pressure steam supply, high-pressure steam is used to supplement the requirements of the turbine. Here, again, a condensing plant is required, but in this case the capital expenditure will in many instances be recovered as a result of the utilization of the low-pressure steam.

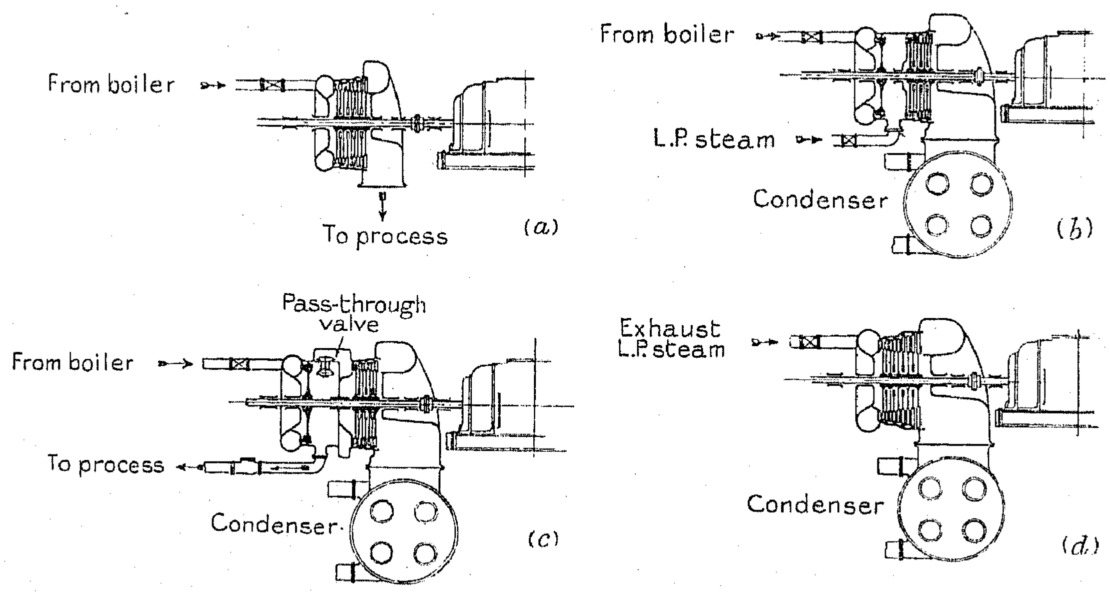

Fig. 1.

(*a*) Back-pressure turbine. (*b*) Mixed-pressure turbine. (*c*) Pass-out turbine. (*d*) Exhaust low-pressure turbine.

(iv) *Low-Pressure or Exhaust Turbine.*

Low-pressure steam only is used in this type of turbine, which also requires a condensing plant. There are few examples of this machine in use, as the application is limited to cases where the electrical load can be adjusted to suit the low-pressure steam supply, just as the low-pressure steam is adjusted in the case of the back-pressure plant.

Digressing for a moment, if a comparison be made between some of the industrial power stations having plant of the previously-mentioned types installed and the public supply undertakings' stations, it will be found that, whilst even the latest super-stations can only show a thermal efficiency of 25–27 per cent as a limit, the industrial stations, relatively small in their output, often show 3 times this figure, owing solely to the utilization of the latent heat of steam.

Commercial Problem of Generating Electricity.

The question of generating electricity with a private plant for works use is one requiring very careful con-

sideration. There must be available cheap fuel, suitable space, and condensing water. Capital charges must be taken into account to include interest and depreciation on plant and buildings, and for this purpose 5 per cent should be allowed for interest and 5 per cent for depreciation, giving a 20-year life for the plant and buildings. To these capital charges must be added the following operating costs: fuel, repairs, wages, sundry stores, transport, disposal of ashes, establishment charges. The cost per unit will also be influenced by the load factor.

Purchased Electricity.

The next problem which will be considered is that of the terms which can be arranged for the purchase of electricity from a public supply authority. In estimating the cost of taking power from an outside source, allowance should be made with regard to capital charges on a private plant, space saved in avoiding the installation of boiler plant and generating plant, and means for obtaining water for condensing purposes. Where space is scarce this should be taken into account when comparing a works cost with the price of purchased electricity.

As it is becoming the general practice to purchase electricity on a 2-part tariff, the maximum demand must be known. In the regulation of the factory load, care should be taken to keep the maximum demand at the lowest possible figure consistent with a satisfactory manufactured product; or, in other words, to keep the load factor as high as possible. These points considerably influence the cost of electricity per unit. The unit charge usually contains a coal clause.

Twenty to thirty years ago the electricity purchased for use in factories was practically all generated as direct current. Whilst the past has been very well served by d.c. supplies, in the future the use of direct current will doubtless in time disappear except for special work, and alternating current will take its place. In fact, this has already happened to a very large extent.

Public supply authorities have found that the most economical method of generating and distributing electrical energy is by means of alternating current, and the consequent development of distribution along these lines has automatically encouraged the use of alternating current in factories on a very large scale. It has resulted in electric motors and starters of the alternating-current type being manufactured on such a large scale that their cost is now far below that of manufacturing direct-current plant.

Type of Supply Used in Factories.

The accepted standard of electric supply in factories nowadays is 400 volts, 3 phase, 50 cycles per sec., for power, and 230 volts, single phase, for lighting, as provided in B.S.S. No. 77—1932. Both of these voltages may, of course, be provided from the same transformer if required. This presents no difficulty with regard to new factories, but in the majority of old factories which were equipped at the time when there were no standards, and alternating current had not been developed to the extent it is to-day, direct-current plant was originally installed; in such cases the change-over to an outside supply presents an expensive problem. A further feature with regard to the future use of alternating-current plant is that a.c. motors are approximately half the price of d.c. motors, and the former are less costly to wire.

Whilst most supply authorities to-day are developing on standard-voltage lines with an alternating-current supply, there are many authorities with large areas which give a direct-current or other non-standard supply, e.g. single-phase with a frequency other than 50 cycles per sec.

Large industrial companies with works in many parts of the country, when laying out their electrical installations endeavour to standardize the electrical equipment used in the various factories in order to keep down the capital expenditure, and to reduce the number of spare machines required. In this connection it is appalling to find how some of the supply authorities are lacking in developing their supplies on modern standard lines. It is acknowledged that the Central Electricity Board has already accomplished a great deal with regard to frequency standardization. It is an astounding feature that firms of this description, when negotiating with supply authorities for the supply of electricity, find such varying charges. There appears to be a demand for some united effort to level up the electricity charges in the various towns; even allowing a load-factor argument as to the charges for electricity, there are large differences in the power charges. The difficulties are very much greater when charges for lighting are taken into consideration—one supply authority will bring the rate in at the same rate as power; another supply authority will give a low rate for power and charge a higher rate for lighting. Many supply authorities are actually offering electric lighting to factories at charges of 3d. and 4d. per unit, whereas the factories themselves can generate at not more than 1d. per unit. Attention to these rates of charges for electricity by the supply authorities would further encourage the industrialist to take a supply of electrical energy from a public supply undertaking.

It is to be hoped that the introduction of the grid tariff and the interconnecting of the various supply undertakings will play some part in levelling up the electricity rates in the future, as the grid tariffs come into operation.

It is quite a common feature for companies with works in various towns to find that it pays in some cases to purchase their supply from outside, whereas in others it pays to generate their own electricity. The industrialist is waiting for a cheap supply of power, and when this is available he will avoid putting down plant for generating power and go over entirely to public supply.

Conversion from Steam to Electric Drive.

In the majority of works where steam-engine drive is employed for industrial machinery, it is accepted that economy in operation would be effected by a change-over from steam to electric drive. The exception usually occurs in the case of the back-pressure plant which exhausts to the factory process mains, thus giving a high thermal efficiency. On the other hand, the most fruitful source of economy obtainable from electric

drives is to be found in the older type of large mill engine driving a number of looms or other machinery. In between the two examples quoted, there may be found steam-driven plant which could be changed over to electric drive with varying degrees of economy.

The principal advantages of the electric drive in industry compared with steam drive are:—(i) Lower operating costs; (ii) lower maintenance costs, particularly where the constant-speed a.c. motor is employed; (iii) absence of stand-by heat losses.

Power Drives.

The question of how best to drive machinery by electric power calls for careful consideration. The old-time practice of power drives in which steam engines, gas engines, and other forms of prime movers were used, employed in most cases long lengths of shafts, reduction gear, shaft extensions driving a large number of machines in which the shafting was hundreds of feet in length, and a large number of leather belts. Failure of the prime mover or some portion of the mechanical transmission meant a 100-per-cent shutdown, seriously interfering with production and temporarily disorganizing a business, with resultant labour losses. These prime movers when removed are often replaced by a large electric motor, as this method involves the lowest capital outlay to convert from steam-engine to electric-motor drive; the drawback of the 100 per cent shutdown also applies in the event of the electric motor giving out, and the mechanical transmission and losses of the original drive are retained.

Modern practice usually provides for a motor to drive each independent machine. This eliminates the risk of 100-per-cent breakdown, and also mechanical transmission with its attendant losses and repairs. Small motors are cheap, can be kept in stock, and are easily and quickly replaced in the event of breakdown, so that there is no anxiety with regard to a shutdown interfering with production.

If we examine the difference between group and individual drive, we find that the former can be installed with a lower expenditure on electrical equipment than is the case with the latter, but the following factors should be taken into account. When group drive is adopted, additional costs are incurred due to fitting overhead shafting, hangers, bearings, and belting, with the necessary labour cost for lubricating, belt repairs, and renewals. Also, when a building is to house a number of machines, the ceilings or roof above must be increased in strength in order to carry the weight and stresses due to overhead shafting, which creates an increased capital expenditure on the building side. Should the building be an existing one, or a new one designed before the type of plant to be installed has been fully considered, then it is necessary to reinforce the ceiling or roof strength by columns from the floor below, with the necessary steel-work for stiffening above, to carry the mechanical transmission of power.

For example, if 100 h.p. is required to drive 10 machines (see Fig. 2), then it is very much cheaper to purchase a 100-h.p. motor with its control equipment than ten 10-h.p. motors with their control equipment, the cost ratio being 1 to 1·85 with semi-enclosed motors, allowing 600 r.p.m. and 1 000 r.p.m. respectively. In the case of the 100-h.p. motor it is necessary to add additional cost, overhead shafting, belting, necessary lubricating, and maintenance costs; the fear of 100-per-cent shutdown must also have a value. The total costs are as shown in Table 5.

Considering the alternative of 10 separate electric unit drives, it is not probable that at any particular period more than one of the 10 motors will be out of commission owing to breakdown, and on this assumption the risk of failure may be said to be 10 per cent as against 100 per cent with one 100-h.p. motor. In the case of the one 100-h.p. motor 100 per cent spare plant is to be carried, whereas in the case of the ten 10-h.p. motors the corresponding figure is only 10 per cent. A further advantage of the individual drive is that it provides a flexible scheme: thus when the manufacturer finds there

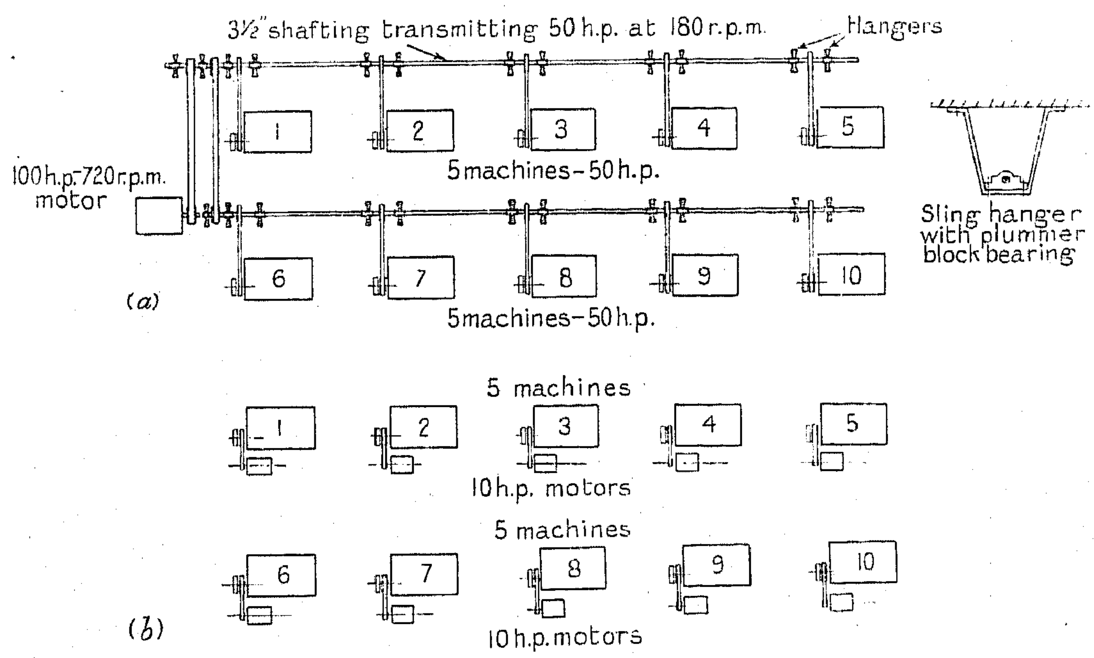

Fig. 2.
(a) Group-drive: ten machines. (b) Independent-drives: ten machines.

is trade variation he can arrange the number of machines to be operated to suit the manufactured output, cutting out all stand-by losses such as occur with the group drive. Whilst individual drives are proving to be the more popular, there are instances where a number of small machines might be grouped together, the number of groups in operation being arranged to suit production and operating as group units.

TABLE 5.

Equipment	Cost for 10-h.p. scheme	Cost for 100-h.p. scheme
	£	£
Squirrel-cage semi-enclosed motor	15	115
Contactor Direct-On starter ..	13	60
Wiring and erection	20	85
Total per motor	48	260
Total electrical cost	480	260
Shafting, pulleys, belting, etc. (including erection)	—	260
Spur wheels and pinion gears (5 : 1)	80	—
Total cost of installation.. ..	560	520
Cost of stand-by motor	15	115

As regards safety in the factory, there appears to be no question that the individual drive is the more desirable system. Belts, shafting, and pulleys, form a prolific source of accidents, such as clothing catching in shafting, belts breaking, etc., with unfortunate results to the operatives. With the individual drive, moving parts may be safely enclosed, with a decidedly beneficial effect on the operatives from the safety and psychological points of view. Competent authorities on factory safety have expressed themselves as being in complete agreement with this statement.

Summing up, the advantages to be gained by using the individual drive are: (*a*) Elimination of mechanical transmission losses, with increased production for a given power consumption. (*b*) Cost of belt drives and overhead shafting eliminated. (*c*) More constant speed, with production of more even material in the case of textile factories. (*d*) Greater reliability in operation and less risk of general breakdown. (*e*) Lighter roof and column construction. (*f*) A great improvement in the lighting and in the cleanliness and general appearances of the plant, owing to the elimination of the belt transmission. (*g*) A greater margin of safety. It will be found in the majority of cases that the advantages of individual drive far outweigh those of the group-drive system.

Fig. 3 gives some idea of modern practice in industrial power drives.

The power drives of such machines as combinations of conveyors, elevators, and automatic weighers, call for very special consideration. Such a combination can be operated in several ways, and it calls for a selector switch control to select the sequence required. For a combination of, say, 10 or 12 conveyors or elevators working in series, each being provided with its own individual motor, special control gear is required; because in the conveying of material from one conveyor or elevator to another, in the event of one failing, the materials conveyed will cause considerable damage to the conveying system by jamming. This calls for the introduction of an electrical interlock arrangement. The modern practice is to arrange all electric drives (preferably positive) with remote automatic controls, the automatic starters being placed together in a central

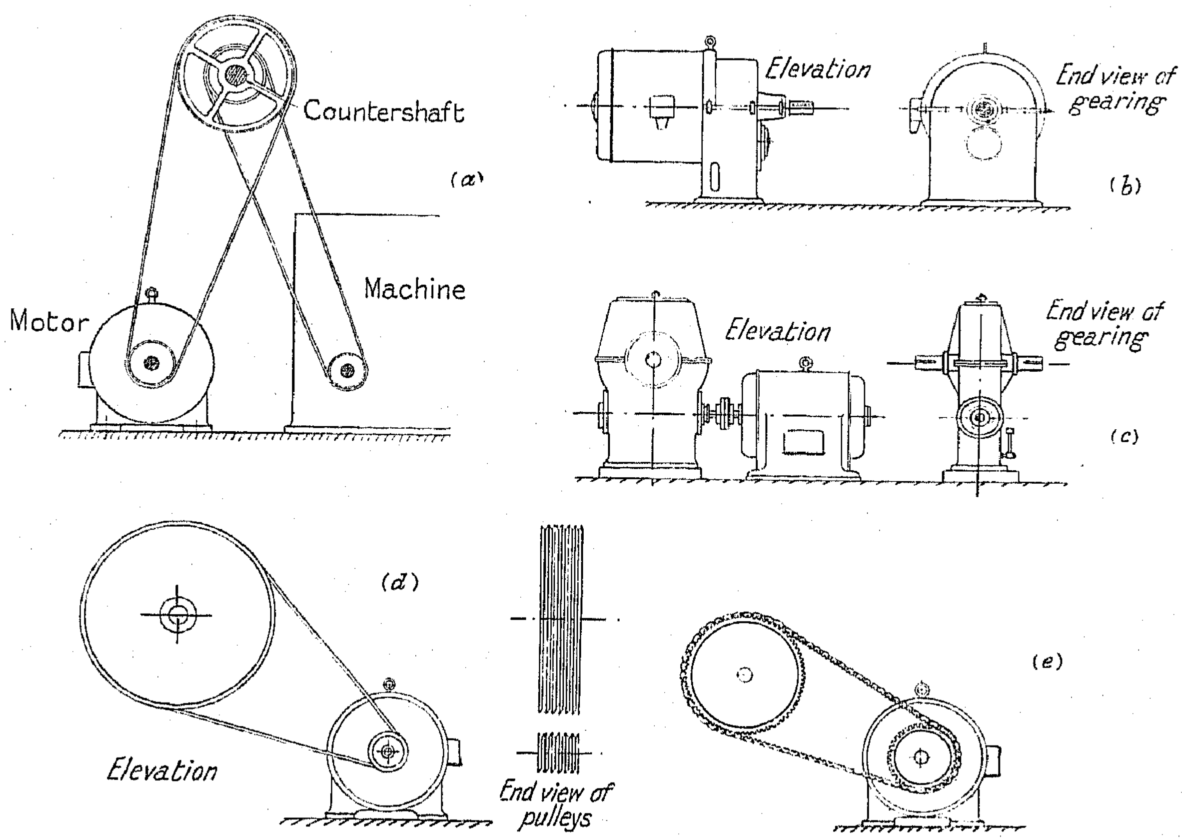

FIG. 3.—Various types of machine drives.
(*a*) Countershaft belt drive. (*b*) Helical-geared motor. (*c*) Worm gear and motor: separate units. (*d*) Tex-rope drive. (*e*) Chain drive.

position, and the control being by means of remote starting buttons with selector switch arrangements fitted in a central position for operating. Throughout the system, remote stop buttons are arranged so that the system may be stopped from any part of the plant in the event of an emergency arising. Each automatic motor starter is electrically interlocked, and, in the event of any one motor failing in the sequence, it automatically stops the preceding conveyors and elevators to prevent piling-up and jamming; the following conveyors and elevators are allowed to continue and empty themselves.

Conveyors are largely used in factories to-day so as to reduce labour costs, and goods are carried hundreds of feet, either by gravity conveyors or by power-driven conveyors. In the case of the single conveyor driven by an electric motor, it is customary to arrange automatic stop buttons at intervals throughout its length for emergency use.

Automatic push-button control is employed to avoid the loss of time in walking round a series of machines to start and stop them with ordinary motor-starting gear. The operator is provided with a push button in a central position which operates automatic starters, so that any individual machine in a group can be picked out and started or stopped when necessary. Electrically-driven machines which require frequent starting and stopping are best fitted with automatic controls, which save time and make for higher outputs of manufactured goods.

Types of Electric Motors, and Their Suitability for Driving Different Types of Machines.

Owing to the multiplicity of types of machines for use in industrial works, very careful consideration is necessary in selecting the correct type of electric motor for the work under consideration.

In the case of direct current, omitting electric cranes, which mainly use series or heavily compounded motors, the selection of suitable electric motors usually rests with two types, viz. shunt-wound or compound-wound motors, either of which can be arranged for variable speed by means of shunt field control. The needs of machines requiring a heavy starting torque can be suitably met by using a shunt-wound motor suitably compounded.

The problem becomes rather different when electric drives by means of alternating-current motors are under consideration, as the torque produced by means of an alternating-current motor varies from that of a direct-current motor. In many cases where motors are direct-coupled to a machine the ordinary squirrel-cage motor is unsuitable, as sufficient torque is not provided in a starting position to get the machine away. In cases of this type it is necessary to fit either a squirrel-cage motor of the high-torque type, which will produce a much higher starting torque than that of the ordinary squirrel-cage type, or a slip-ring type of motor. The torque characteristics of these three types of motors are shown in Table 6.

When selecting an a.c. motor for a particular drive, great care is needed to ascertain the power required for starting up the machine, and to make sure that the motor will provide the torque necessary. A further noteworthy feature with regard to starting torques is the heavy current required, which is likely to cause fluctuations in the line voltage to the wiring system unless the latter is suitably designed.

In cases where it is only possible to use squirrel-cage motors, which may not provide a suitable starting torque, these can be fitted with centrifugal pulleys so that the torque is available when the motors have attained or are approaching normal speed.

In instances where high-torque motors are used with a heavy starting current, care must be taken that stresses are not set up owing to the hammer-blow effect of the motor drive jumping into speed before actually taking up the load. For this reason such motors are not suitable for electric-crane work. This trouble can be obviated somewhat by the careful adjustment of auto-transformer tappings, or by the introduction of the inductor type of starter.

The problem of machines requiring a variable speed, so that the output of the manufactured product may be varied, is easily met by a direct-current shunt-wound motor. With alternating current, speed variation may be obtained in three ways: (i) pole-changing, which changes the speed in steps, and which is seldom suitable; (ii) by means of a commutator motor, in which speed control can be obtained on very similar lines to the shunt-wound direct-current motor; (iii) variation of the slip-ring speed in steps (this method has its attendant rotor resistance losses).

Variable-speed a.c. motors of the commutator type are expensive, but it is satisfactory to note that to-day, with their increased use, the manufacturing cost has been considerably reduced. It is anticipated that in the early future the variable-speed a.c. motor will be no more costly than the ordinary shunt-wound, variable-speed, direct-current motor. This is an important factor, as there is a large demand for variable-speed control on most machines in industrial works to suit the product under manufacture, owing to variation in quality of

Table 6.

*Torque Characteristics of A.C. Motors.**

H.P.	R.P.M.	Squirrel-cage type				Slip-ring type, with percentage of rotor resistance in circuit	
		Ordinary		High-torque			
		Times full-load torque	Times full-load current	Times full-load torque	Times full load current	Times full-load torque	Times full-load current
1	1 400	1·3	4·25	2·0	4·5	2	2·7
5	960	1·25	5·75	2·0	4·5	2	2·7
10	960	1·25	6·5	2·0	5·0	2	2·7
25	720	0·9	4·5	1·75	4·3	2	2·7
50	720	1·0	5·25	1·75	4·5	2	2·7
75	580	1·05	7·2	1·75	4·5	2	2·7

* The figures given indicate the starting torque when the motor is switched directly on.

raw materials, and in many cases owing to changing atmospheric conditions.

The slip-ring motor is losing favour owing to the fact that, when set for constant speed, it is liable to vary with every variation in load. In operation it is similar to a d.c. motor operating through a series resistance.

A further consideration which must be taken into account when introducing electric drives in factories, is the nature of the goods to be manufactured. Where these give off dust which may be exploded by ignition (I am making no reference here to coal mines) dust-proof motors are essential. There are two types available, namely, the explosion-proof type, and the fan-cooled enclosed type (see Fig. 4), the latter being suitably designed to prevent the ingress of dust.

In places where there is a dusty atmosphere which forms an explosive mixture, the electric motor (see Fig. 5) must be fitted in a separate building, which should be well ventilated. This is usually erected adjacent to the main building, and the driving shaft fitted with glands where it enters through the main-building wall.

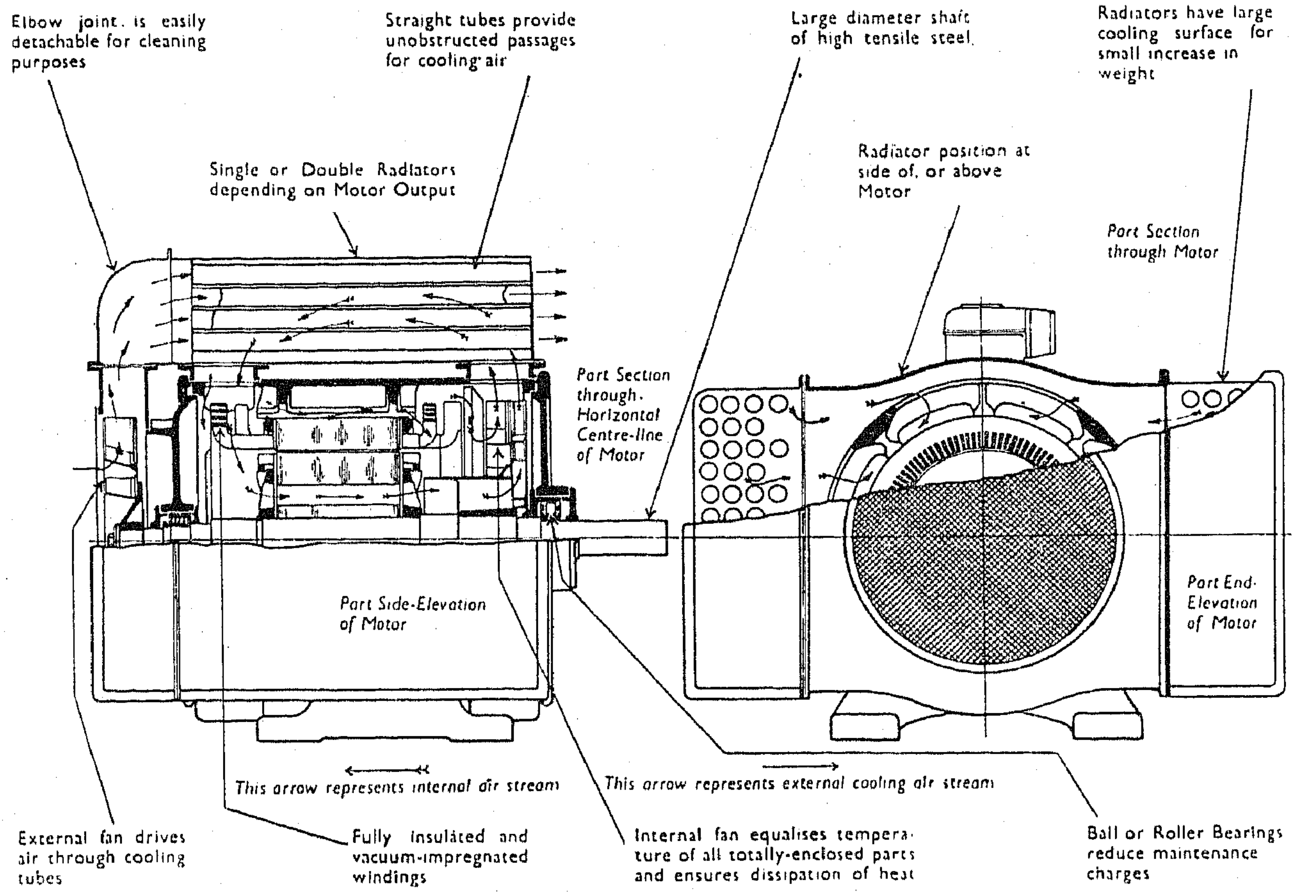

FIG. 4.

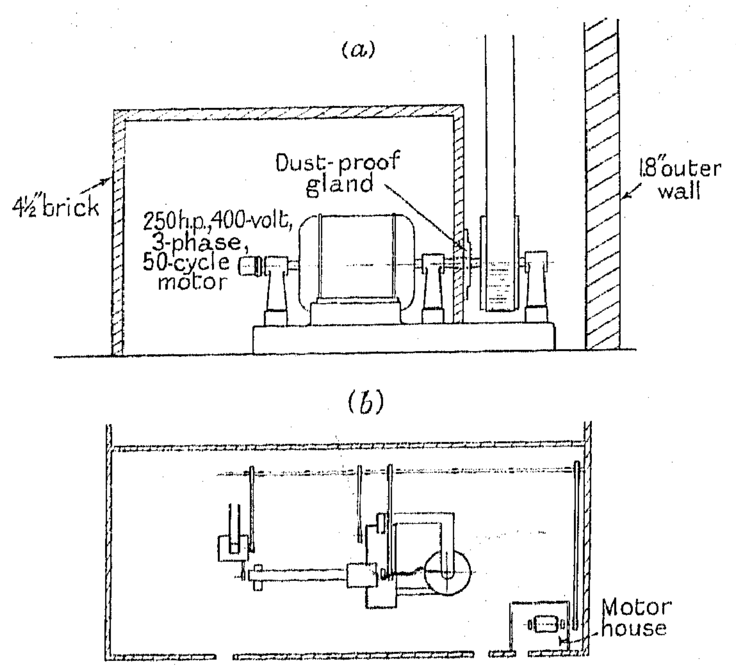

FIG. 5.

(a) Sectional elevation of dust-proof motor house.
(b) Plan of grinding plant, showing general arrangement.

MOTOR CONTROL GEAR.

In connection with the control of electric motors by means of motor starters, for industrial work it is good practice to arrange for all control gear to be ironclad and totally enclosed, as any ingress of dirt creates a high maintenance cost. Where there is no danger of breakage, glass windows may be fitted in suitable metal frames to enable the maintenance staff to observe whether any contacts which are in operation require attention. Motor starters and gear are very difficult to keep clean, and therefore maintenance charges can be considerably kept down if the correct type of plant is used.

LOW-VOLTAGE ELECTRICAL DISTRIBUTION OF POWER IN FACTORIES.

This is usually carried out as follows:—

Exterior Distribution.

(1) Overhead cables carried on poles.

(2) Paper-insulated and armoured cables laid underground.

Either of these types of distribution system should have a life of 25 years.

Interior Distribution.

(1) Vulcanized-rubber cables carried on insulators fixed to walls or ceilings.

(2) Cables run in steel conduit.

(3) Lead-covered cables (not usually satisfactory).

(4) Specially prepared cables, resistant to chemical action.

I.E.E. Regulations and Home Office Regulations.

When wiring factories, it is good practice to observe the I.E.E. Wiring Regulations, and also the Home Office Regulations for the use of Electricity in Factories and Workshops. It is also useful to look over the Annual Report of the Chief Inspector of Factories and Workshops, which elucidates the cause of many accidents due to weakness in the construction of electrical wiring systems and apparatus for use in factories.

Plant Inspection.

Operators in charge of process work are not capable of reporting when a repair is necessary to the electrical equipment. They are only able to report when a machine actually breaks down and stops. To leave it to an operator to report on the electrical equipment will result in high maintenance costs, and therefore some system of plant inspection should be put into operation.

A plant inspector usually inspects and reports on all electrical equipment, and on receipt of his report any repairs which may be necessary are put in hand. In this way serious breakdowns are avoided; usually the repairs are of a minor nature.

A sound system of plant inspection helps to ensure that the output of a factory is maintained. It can be said that the driving of works machinery by electric power is to-day the most reliable method, and that the speed and output of the plant are maintained more nearly constant by electric drives than by any other method.

Industrial Lighting.

The efficient lighting of factories is of much greater importance than is generally realized by most manufacturers. The percentages of the total working hours per annum during which artificial lighting is required are approximately as follows: 24-hour working, 46 per cent (3 shifts); 16-hour working, 31 per cent (2 shifts); 8-hour working, 12 per cent (1 shift).

It can be generally stated that the cost of lighting is a very small percentage of the total manufacturing cost, usually well under 1 per cent, and the extra cost of good as compared with bad lighting should easily be recovered by increased output and improved quality of the goods manufactured. If we take, for example, a general office in which there are 200 clerks employed, with a total wages bill per annum of approximately £30 000, the cost of the lighting only represents 0·34 per cent of the wages bill.

To-day the most popular form of factory lighting is gas-filled lamps housed in suitable fittings and correctly spaced to give ample lighting, the important feature being to arrange these at a suitable height and in such a way that when people are moving about a room, or at work, they are not blinded by the glare of the lamps. There are numerous suitable fittings on the market to-day which were not available a few years ago.

With regard to the quantity of light required, this varies considerably with the type of work which is being carried out. As an example, the manufacture of fine articles such as textiles, toilet requisites, foodstuffs, etc., requires good lighting. In rooms where the packing of these materials takes place, a lower intensity of lighting is required, and in the warehouses where the packed goods are stored a still lower intensity of light is required; this indicates that careful grading of lighting in all departments is necessary. An important feature with regard to lighting inside factories is the avoidance of large lighting units with their objectionable glare.

Manufacturers should give careful consideration to the interior decorations of the factory; the absorption of light by dark-coloured surfaces, dirty walls, etc., gives rise to a very dull appearance.

Daylight lamps are used only in instances where colour-matching is of importance. Some manufacturers favour the mixing of daylight lamps with ordinary lamps, but a more common practice is to have a small separate room or kiosk lit with daylight lamps where colour-matching may be carried out.

It is considered good practice to have an independent pilot lighting system to enable the main lighting to be entirely switched off during periods when the factory is closed down. Pilot lighting circuits should be arranged here and there on stairways and corridors, with an occasional lamp in large rooms, so that movement about the factory can be carried on during off hours. On the whole the pilot lighting system is a useful service, particularly for watchmen when on patrol duty.

Metering.

The metering scheme is generally so organized as to synchronize with the accounting system, which is used in arriving at the manufacturing costs. It is not usual to find the same system used in all its details in factories or groups of factories under different control. The following gives some general idea of the main divisions into which the electrical energy is allocated in a large factory:—

(1) Receiving and storing of raw materials.
 (*a*) Internal transport.
 (*b*) Storing.
 (*c*) Issuing.
(2) Manufacturing.
(3) By-products treatment.
(4) Packing.
(5) Warehousing and despatch.

The metering will, of course, depend to a large extent on local circumstances, as, for example, whether the supply is public or private; if public, the metering system will vary according to whether power and lighting are recorded on one meter or on separate meters. If the charges are on the basis of maximum demand with a kWh charge, then, in addition to the main maximum-demand meter installed by the supply

authority, it is to the interest of the factory to have a maximum-demand meter installed in each large department, so that excessive maximum demand can be located and dealt with. Another useful feature of this arrangement is that the charges can be fairly allocated between the various departments. In cases where the process is invariably the same in each department from an electrical-energy demand point of view, the regular checking of the maximum demand in each department with one portable type of meter will be satisfactory where economy has to be a stronger point than accuracy of electrical cost allocation. Preferential rates should be given to departments which have a high load factor, these usually working two or three shifts per day and during week-ends. It is as a result of their operation that the factory as a whole receives current at rates which are lower than they otherwise would be.

The recording type of meter is very useful in a large factory; it may be used as previously indicated to lower the factory maximum demand, and is a valuable asset generally in any attempts to lower the electricity costs by rearrangement of factory routine.

In cases where the agreement for the supply of electricity includes a power-factor penalty/bonus clause, a portable power-factor meter is of great assistance to the works electrical engineer as a supplement to the main power-factor meter.

Whilst there is, of course, an economic limit to the number of meters which may be installed, a reasonable amount of detailed metering will repay the necessary expenditure. It should be noted that, with respect to metering, electricity enjoys a decided advantage over competing forms of energy where cheapness and reliability are concerned, and the meter indications form a reliable basis for production costing.

Temperature Control of Manufactured Goods.

Heat is applied during some part of most manufacturing processes. In the past the process was changed from one temperature to another by the operators' experience and judgment, and whilst in the past this may have proved fairly satisfactory, it is found that errors arise creating a percentage of "spoils," and the articles when finished are not uniform. Excellent instruments, in the form of resistance thermometers or thermocouple pyrometers, are on the market which enable accurate temperatures to be observed at any desired stage in process manufacturing. These temperatures can either be indicated and logged, or, if of sufficient importance, be recorded by chart. A reference to these charts or logs from time to time will show whether the application of heat is being continually carried out, both summer and winter, at the correct temperatures.

In many types of manufactures in which the temperature-range may vary from 500° F. down to atmospheric temperature, during the period of falling temperature there may be as many as 12 process operations, and each one should be carried out at its correct temperature.

Electrochemical and Electrolytic Work.

Where the supply is alternating current, and direct current is required for electrochemical and electrolytic work, it may be obtained from rotary convertors, motor-generator sets, or mercury-arc rectifiers. Recent developments of the latter have provided a large voltage-range by means of "grid voltage control."

Telephones.

Space does not permit of more than a passing reference to telephones. A good telephone service creates savings in time which must result in the more efficient working of the factory. In intercommunication between factories in various parts of the country, the teleprinter is a useful asset and one on which the Post Office is to be congratulated.

Conclusion.

It has only been possible in the time available to deal with some of the more important phases of electricity as it affects industry. Such widely differing aspects as cooking for the factory workers; electric clocks giving synchronized time, coupled with time-recorders; equipments for the purpose of factory protection during non-working hours, such as fire alarms and tell-tale devices; portable apparatus; the heating of buildings; power-factor correction; mining; and metallurgical furnaces; all enter into the activities of the industrial electrical engineer.

Undoubtedly, electricity is taking an increasingly large part in industrial life owing to its higher efficiency, lower cost of application and operation, and greater convenience when compared with competing forms of energy.

With the completion of the grid it is to be hoped that the "cheap and abundant supply of electricity" which was promised will materialize, and will enable the British manufacturer to compete effectively with his rivals.

WESTERN CENTRE: CHAIRMAN'S ADDRESS

By R. HODGE, Member.

(ABSTRACT *of Address delivered at* BRISTOL, 15*th October*, 1934.)

I feel that I should not be doing justice to those to whom we owe great homage—those who did the pioneer work, often in the face of considerable difficulties, in order to lay the foundation of that great electrical industry in which we to-day are engaged—if I did not briefly indicate the main scientific developments which formed those foundations; and I hope that I shall not be thought unduly prejudiced if I try to show how these have been, if not actually laid, at least strengthened and built upon by the manufacturing branch of the profession.

As we all know, the industry rests on a firm scientific basis, but its origin is lost in obscurity. The Chinese are supposed to have been familiar with the magnetic compass; and it is fairly certain that the Greeks knew something of the phenomena of static electricity; but the first record of any value in this country was made at the end of the 16th century by Gilbert, who gave an interpretation of some of the effects of magnetism and electricity.

The true foundations of modern electrical engineering, however, were laid by Michael Faraday (1791–1867). Faraday, whose scientific work was carried out at the Royal Institution, evolved a theory of electromagnetism and verified it experimentally. It was he who constructed and operated the first dynamo. In the field of an electromagnet of the type invented by Sturgeon in 1825, Faraday rotated a copper disc which had one spring contact on its axis and another on its periphery. The two springs were connected to a galvanometer, and this demonstrated the flow of current. This was the forerunner, in 1831, of the modern dynamo; but many years were to elapse before dynamos for power purposes were constructed. The earliest commercial results of his discovery were in the field of communication.

In the same year, 1831, Faraday discovered the phenomenon of electric induction, thus opening up the way for the induction coil, and, at a later stage, the transformer and allied apparatus. His discovery in 1834 of the laws of electrolysis led to the development of the modern industry of electroplating; whilst his discovery of specific inductive capacity in 1836 led to important developments in submarine and buried cables.

Between 1850 and 1860 many attempts were made and much effort was expended on the problem of increasing the intensity of the current obtained by electrodynamic induction.

An important stage in this work was reached in 1867, when Henry Wilde of Manchester showed to the Fellows of the Royal Society some remarkable experiments with his " dynamo machine " and illustrated the great potentialities of electricity.

The first electric cable for communication was laid from Dover to Calais in 1851, and Atlantic cables followed as early as 1858 and 1865, but it was Bell's invention of the telephone in 1875 to 1876 that marked the beginning of a new era in communication. The first arc lighting in Great Britain was effected in 1862; but in Paris not until 1876. Then in 1878 the Edison-Swan Electric Light Co. was formed; and Edison in U.S.A., and Swan in England, made their first incandescent electric lamps.

An epoch-making event in the history of electrical engineering was the construction by Ferranti of generators giving 100 amperes at 10 000 volts for the Deptford power station. These machines were manufactured in 1890, and went into commission on the 16th February, 1891.

In 1884, Sir Charles Parsons took out his first two patents for the turbo-alternator set. It is to these inventions that we owe the modern steam-driven power station, which has resulted in such wonderful economies in running costs. By 1899 a turbo plant of 1 000-kW rating was being built. This had increased to 4 000-kW rating in 1907, whilst in 1925 a 25 000-kW set was constructed. At the present moment the largest turbo-alternator set which has been made has a capacity of 200 000 kVA in a single unit, though the largest in Great Britain is one of 105 000 kW, which is now under construction.

I now want to turn to transformation and conversion, and first of all to deal with switchgear. Prior to 1897, almost the only form of circuit breaker in use was of the air-break type; this gave a long arc, even at comparatively low voltages, but the immersion of the contacts in oil was in use in that year, and this has obtained right up to the present day.

Then came an innovation of considerable importance in the operation of these oil-filled circuit breakers. This was the " explosion pot " breaker. For a given rating this type allowed the circuit breaker to be considerably reduced in size.

Years ago theoretical and experimental work on the de-ionization of the electric arc was carried out by Slepian, and so we find that breakers operating on the de-ionizing principle are available to-day in large sizes.

Other breakers worthy of mention are the oil-blast breakers, which operate on the principle first introduced by Ferranti soon after 1900. The recent improvements in these breakers are great, and the credit for this must be given to Wedmore and Whitney.

On the Continent, considerable attention has been devoted to gas-blast and air-blast breakers, where the blast is introduced through one of the contacts. To these, too, noteworthy improvements have been effected, and satisfactory performances obtained.

While all this work was occupying the attention of research workers in the alternating-current field, d.c. development was less spectacular; the improvements of note during these momentous years were the introduction of arc shields and the magnetic blow-out, which led the way to the development of high-speed circuit breakers.

The safety of the operator has received considerable attention from manufacturers in the last 20 years. The truck type of cubicle was introduced into this country in 1903. Two years later the earliest metalclad unit was built. This was a development following on from the truck-type cubicle and has been constructed with a rupturing capacity of 2 000 000 kVA or more.

The last few years have been notable for the development and extensive application of outdoor types of switchgear. This is particularly noticeable in high-voltage apparatus, where the need of adequate clearances renders the cost of buildings practically prohibitive.

The modern tendency of interlinking power-supply stations has brought into prominence the necessity of close attention being given to circuit-breaker design, and this, in its turn, has led to the establishment and formation of testing companies, these companies, of course, being capable of supplying the requisite amount of power necessary to test large breaking-capacity switches.

Another development on a large scale during the last decade has been that of automatic and remote-controlled substations; which development has been and, of course, is of considerable value to the supply branch of the industry.

Before proceeding to the subject of conversion, I must say something about transformers. Their essential principle of operation was discovered, like so many other fundamentals, by Faraday. This was in 1831, and yet not until 1882, when Garland and Gibbs patented a system of using transformers, were they applied for any serious commercial purposes.

We can get some idea of the rapid developments that have occurred from the fact that, whereas in 1891 Ferranti was designing transformers of 150 h.p., by the end of 1932 the largest transformer built in England was rated at 93 750 kVA. The result of the improvements of the last 40 years has been to reduce per kVA the overall size, the weight, and the cost of transformers. This, of course has been the tendency of most other electrical apparatus. The consequent savings in the cost of generation and distribution of electrical power have been by no means negligible.

An important landmark in the history of transformer development was the introduction, about 1908, of alloy steel. This had a high resistivity and was employed to replace the transformer iron previously used. As a result, not only were the losses reduced, but the necessity for dismantling the transformers in order to anneal the cores was avoided. The greatest benefit achieved, however, was in the economic results which followed. By its adoption the size of the transformer was reduced enormously. Consequently, less floor-space was required, and this reduced the cost of housing and the amount of land needed. The cost of shipping and transportation was also lessened; this constitutes a very great item when it is realized that the electrical industry relies to a large extent upon its export trade.

A recent advance in the design and construction of transformers has been in the provision for cooling. A departure has been made from the previous practice of using self-cooling transformers; the cooling is now effected partly by oil and partly by forced air-blast. This is another factor allowing the total size of the unit to be reduced.

A comparatively recent improvement has also proved to be of the greatest importance. I refer to the development of on-load tap-changing gear. Time, however, prevents enlargement upon what, after all, is something of a specialist's subject.

It is open to question whether any other type of electrical apparatus has seen so many fundamental changes as we have witnessed in the machinery for the conversion of alternating current to direct current. By the use of this type of apparatus it is possible to generate alternating current and transmit it efficiently, converting it to direct current before use, so as to have the benefit of certain advantageous characteristics of direct current. For a long time where reasonable powers were concerned the rotary convertor and transformer on the one hand, and the motor-generator or motor-convertor on the other, between them held the field. The full-load efficiencies of these two devices were approximately 94 per cent and 90 per cent respectively. They have lately been displaced to a large extent by the mercury-arc rectifier, which has a higher efficiency, about 96½ per cent. These rectifiers have already been made in sizes up to 3 000 kW, and the advances in this branch of engineering are so rapid that we may soon expect a higher figure. A grid-controlled rectifier, using either a mercury pool or a hot cathode, is being developed rapidly for increasingly larger sizes and for higher voltages. Some of its characteristics are extremely useful and, by suitably controlling the grid potential, it becomes available for a variety of uses. The copper-oxide rectifier introduced by Grondhal in 1927 has been developed commercially for use where comparatively low voltages and currents are required, and the work that is now being done justifies us in foreseeing the copper-oxide rectifier in use with higher powers and greater voltages.

In view of the fact that much of the increasing electrical consumption can be traced to special tariffs, which call for maximum-demand instruments and prepayment meters, it is interesting to speculate how far this has been assisted by instruments developed by the manufacturers themselves. Certainly the development of integrating meters has been a most important factor in the commercialization of electrical energy. To-day there are available compact and accurate instruments at reasonable prices and of robust construction for any special requirements, and the indications, if necessary, can be recorded hundreds of miles from site. It was by the development of such apparatus that the present interchangeability of loads between different transmission systems is possible, and particularly is this the case with automatic substations. The growth of these raised many problems in the field of relay and protective gear; and one of the most notable developments was the

Translay system, which can be used on both underground cables and overhead mains.

When one considers electric power-using apparatus there is the same story. From a consideration of the weight of a normal-sized motor at successive stages in the history of its development we can get some idea of the improvements that manufacturers have made in electric motors. For example, a 5-h.p. motor in 1893 weighed 400 kg (882 lb.). In 1928 a similar-sized motor weighed 70 kg (154 lb.), whilst in the next five years, by 1933, the same size of motor had been further reduced to 40 kg (88 lb.). This striking decrease in weight, for the present-day machine has been brought down to a weight of about one-tenth of that of the corresponding machine 40 years ago, has brought the community incalculable benefits: less space is needed; the first cost is only a fraction of what it was; and running costs, owing to the greatly decreased losses, are similarly reduced.

The improvements in electric motors have, of course, had their influence on electric traction developments. The development of regenerative equipment and the many improvements in control gear, together with the increase in reliability that experience has brought about, the improved units which have been developed, and other individual items in this connection which are too numerous to mention, have resulted in a very widespread application of electric traction. Commencing with tramcars, they led to its extensive application to suburban and main-line electrification. One may instance here the London to Brighton line, the first main-line electrification scheme in Great Britain where, with axle-mounted motors, running speeds of 70 m.p.h. have been reached, while a service to the coast in one hour is part of the regular timetable. One of the great difficulties of electric traction was the transmission between the motors and the axles; but the electrification of this stretch is a striking example of how the difficulty has been overcome.

Many laymen imagined that the day of the electric tram was over, and they talked glibly of the superiority of the petrol-driven omnibus, but regenerative equipments, which have been supplied for tramcars, show a saving of 30 per cent in power consumption, together with simplified driving and less wear on the brakes. This development is giving a new impetus to this branch of the industry, and the economy in running cost should save the trams from being driven off the roads for some time to come. Trolley-bus developments warrant the serious consideration of transport engineers, and whilst the trolley-bus takes rather more electricity than the rail-tram, yet it obviates the necessity of laying an expensive track. The indications are that this mode of transport will become increasingly popular.

Although considerable advances have been made in the development of electric propulsion for ships, the most marked tendency has been to adopt electrical apparatus for auxiliary marine equipment, and it is interesting to note that the new Cunarder, "Queen Mary," will have nearly 28 000 h.p. of electric motors in use on board. A notable development, and a comparatively recent one, has been the gyro-stabilizer in the Italian ship "Conte di Savoia."

Let us now consider a subject that affects us all—lighting. No account of electrical developments would be complete without mention of the electric lamp. The electric power industry, as we know it to-day, grew out of the invention of the incandescent electric lamp. In their beginnings, the central stations were mainly, if not solely, concerned with the supply of electricity for lighting. The first lamp, an incandescent carbon filament, existed for a long time in a comparatively inefficient form. A great advance was made when drawn-wire tungsten vacuum lamps were introduced. These had an efficiency of $1\frac{1}{4}$ watts per candle. Then in 1913 the invention of the gas-filled filament lamp brought about a tremendous increase in efficiency, the watts per candle being reduced to between 0·7 and 0·8. Another increase in efficiency of approximately 20 per cent has been brought about in recent months by the invention of the coiled-coil filament lamp, and it is anticipated and hoped that experiments which are now being made, employing rarer gases than those now in use, will lead to still further improvements in the efficiency of the electric lamp. Another development is the new discharge lamp, which gives an output of about 40 lumens per watt. This corresponds to a light output of 2·7 times that of the tungsten filament lamp of the same wattage, and its efficiency is very much greater than that of any other form of lighting hitherto produced on a commercial scale, though, at the moment, the use of these discharge lamps is only applicable to special cases.

All these improvements and developments are the outcome of a vast amount of expenditure of time, money, and effort, on the part of the manufacturing companies, the benefit of which accrues to the community as a whole and to the electrical industry in particular; and, in view of the importance of artificial lighting in the life of everyone, this benefit is of no mean order.

If one considers the great number of developments and improvements that have been effected in electrical apparatus of all kinds, from the largest generator to the smallest tumbler switch, one cannot but marvel at the reduction in cost which has been brought about. Cost is, perhaps, in the first instance the most important consideration, for unless the total cost of electric power to the user is lower than that of all other forms, then its widespread adoption will not occur. An outstanding example of this was the development of the electric induction furnace, which has done so much to reduce the cost of production of high-grade alloy steels.

In addition to the low cost, however, there has to be considered the convenience of electric power. The saving in weight and bulk which has been effected has had considerable effect in its possibilities in traction-motor drives, marine applications, and many other things; in fact there is hardly any use of electricity in which this saving does not play a part. Another feature of the developments which have been made is the increase in load factor which has been brought about by the introduction and development of apparatus which would consume energy during the off-peak periods, with a consequent decrease in the cost of energy production.

Again, think of all the new industries which have been started in this country by the manufacturers. It is not many years since broadcasting was unknown, and yet

only a very small percentage of the population appreciate that its introduction to this country was brought about by a group of the leading electrical manufacturers, who realized its possibilities and to whom alone is due the credit for its inception. It was they who found the initial capital to erect transmitting stations, from which entertainment programmes were radiated; and but for their initiative it is highly probable that broadcasting in this country would have been long delayed. It was due to their public-spirited policy that transmitting apparatus was allowed to be built, though covered by patents held by the respective members of that group.

A further development, following on, and due to the wireless valve, is what is termed "bloodless surgery." Electric currents can now be produced by the aid of the wireless valve, which, when used with suitable surgical instruments, make it possible for the surgeon to cut through practically any tissue of the human body except bone and gristle.

Whilst on the subject of medical electricity, it is interesting to note that high-frequency currents are being used by medical men and radiologists for deep-heating of the tissues of the body, the heat, of course, being produced by the passage of the current through the tissues.

Such a high-frequency current is useful because, differently from Faradism, when the current reaches a critical frequency (which varies with different individuals) the body gives no physiological response.

Medical electrical treatment has progressed, from Volta's cell, through Faradism, to higher frequencies and wavelengths diminishing down to a few metres.

Radiologists are now demanding an X-radiation of wavelength getting closer to the short waves of the γ-rays of radium. Up to a short time ago physicists and manufacturers had been able to produce X-ray tubes capable of operating only up to approximately half a million volts. Manufacturers are now working on the production of X-ray tubes to operate at 1 million volts, and when these have been proved a practical proposition and produce the X-radiation of wavelengths referred to above, then radium, which has a limited application, will be superseded in some directions.

Treatment by radium is restricted to small local areas, with the exception of what is known as the "bomb" treatment; whereas with the emanations from an X-ray tube a much larger area can be radiated.

Recently a new type of high-frequency technique has been brought to the notice of the medical profession. In this a much shorter wavelength is utilized, and medical men have discovered that certain wavelengths have definite lethal effects on particular organisms, organisms reacting differently to different frequencies.

Again, the great impetus received by the cinema industry from the introduction of the talking picture was the result of development by electrical manufacturing companies—a development which to all intents and purposes formed a new industry, or at any rate so altered the complexion of the existing one as to make it almost unrecognizable.

Probably more than any other industry is the electrical industry standardized. This obviously is the work of the manufacturing companies, and is still going on with a view to price reductions and interchangeability.

The industry as a whole possesses a large and progressive research organization, which until recently was mainly supported by the manufacturing side, but the larger manufacturers were amongst the first to establish their own research laboratories to meet their own particular problems.

The foreign developments in application, which until recent years were ahead of those obtaining in the British Isles, were mainly due to the absence of restrictive legislation abroad, and to the existence of more severe service conditions than those experienced in the home market. The experience in design and service operation obtained by the manufacturer from his activities in the export market has thus become available to the problems of the home market. Railway electrification is an outstanding example of this particular advantage, for the manufacturers brought their foreign experience to the service of the electrical industry of this country; whilst the application of high-voltage transmission is another case where the necessary knowledge was obtained from work done abroad.

In view of the growing nuisance of noise in this modern world, the part played by the manufacturing branch in lessening this evil is worthy of notice. Intensive investigations have led to a standard of measurement of sound; and the measurement of sound intensities of machines has in turn led to a very considerable decrease in the noise emitted. Electric motors and meters—to mention only two items—are almost noiseless in comparison with those of a decade ago; and every effort is being made to carry out this principle in electrical apparatus of all kinds.

Fundamental investigational work on the properties of materials, carried out by, or on behalf of, the manufacturing side of the industry, such as steels at high temperatures and pressures, has been one of the major factors contributing to the improvement in turbine design. The extent of this improvement is indicated by the fact that in 1907 the highest steam pressure in use for turbines was 475 lb. per square inch; whereas, to-day, turbines have been constructed for operation at pressures as high as 1200 lb. per square inch and temperatures of 850° F.

A few comparative figures will indicate the advances which have been made in turbine construction throughout the world:—

In 1880 the largest unit built was	60 h.p.
In 1890 the largest unit built was	100 h.p.
In 1900 the largest unit built was	1 650 h.p.
In 1910 the largest unit built was	16 000 h.p.
In 1920 the largest unit built was	45 000 h.p.
In 1925 the largest unit built was	60 000 h.p.
In 1930 the largest unit built was	160 000 h.p.

Another result of the improvements in turbines is in the reduction of the amount of coal consumed. Whereas a quarter of a century ago 18·5 lb. of coal were required to generate one unit of electricity, in 1926 the average consumption was 2·53 lb. To-day, according to the latest returns of the Central Electricity Board, a fuel

consumption as low as 1·12 lb. of coal per unit has been obtained.

Some idea of electrical progress in Great Britain is given by the estimated output in millions of kilowatt-hours by authorized undertakings, the figures being

1920	4 374 million kWh
1930	11 120 million kWh

and although this rate of increase has not been maintained, nevertheless the total output of authorized undertakings during 1933 had risen to approximately 15 000 million kWh.

No attempt to indicate the advantages conferred by the manufacturing section on the electrical industry would be complete without mention of one very important service which that branch has performed. I refer to the part played by this section as a training school for the industry as a whole; a large number of those who hold responsible positions in other branches have received at least part of their early training in the manufacturing section.

It is gratifying to note that our Chairman last year (Mr. A. Nichols Moore) in his inaugural address said that "the manufacturing section should be maintained in a thoroughly healthy condition, and that it should be able to secure a steady outlet and an economic price for its products." One naturally wonders how far such a view is held by buyers of electrical machinery; because immediately any scheme is suggested or put forward to reduce or eliminate unhealthy competition, there is a suggestion that the buyer is being coerced or told from whom, and at what price, he shall purchase his apparatus.

The political tendency in this country has always been towards co-ordination on a voluntary basis; and, though some object to such an idea, I would draw particular attention to some of the alternative experiments which are taking place in different parts of the world. Russia has adopted complete State control; the corporate or corporative State system exists in Italy; whilst Germany has a semi-State control system; and finally in the U.S.A. there is the N.R.A. policy, a policy which the force of circumstances has modified, from compulsion to negotiation, for the fixing of minimum prices—and then only in well-defined emergencies.

The "man in the street" need not fear this rationalization, for it must be realized that in the last instance the consumer is the final arbiter on all price questions.

When one considers all the improvements which have taken place, and to a few of which I have drawn attention in the address, one naturally asks the question: "To whom are these improvements due?" The credit in the great majority of cases must be given to the manufacturer.

The manufacturers, however, cannot do it all by themselves. The supply and distribution sides of the industry are often in closer contact with the daily wants of the people. Often it is their demand for something better, safer, or more efficient, that has guided the researches of the manufacturers or stimulated them to greater achievements. Sometimes an actual suggestion from the distributor can be adopted almost in its entirety. Only by complete co-operation between all branches can the manifold services of electricity be fully exploited. There should be no rivalry; we are working in series, not in parallel, and any break in the chain will cripple the rest.

It is up to each one of us to see that we do not fail this modern but most fascinating of goddesses, to whom we have dedicated our business lives. If we have advanced her cause, if we have spread further her cult, we shall not have laboured in vain.

SOUTH MIDLAND CENTRE: CHAIRMAN'S ADDRESS

By W. BURTON, M.Eng., Member.

(ABSTRACT *of Address delivered at* BIRMINGHAM, *17th October*, 1934.)

INTRODUCTION.

I offer my sincere thanks to the Committee and members of the South Midland Centre for having paid me such a compliment as to elect me Chairman of the Centre for the coming session.

As the chairman's address is not open to discussion, I shall endeavour to avoid controversial subjects and to confine my remarks to the progress of the industry in which we are all engaged. A noticeable feature is the way in which "light current" engineering and "heavy current" engineering assume importance alternately. In 1871, when the Institution was founded as the Society of Telegraph Engineers, and the main source of current supply was the primary battery, measurements of current and voltage had quite small values. Nowadays, we have currents of many thousands of amperes associated with voltage figures of similar magnitude.

Early experimenters dealt almost entirely with unidirectional currents, and the conception of an induction coil was a piece of apparatus which, by making and breaking a direct current at low voltage, induced in a secondary coil a high voltage, still unidirectional at "make" and unidirectional (but with opposite sign) at break.

For a time the "light current" engineers held the field, but the development of the dynamo opened up an immense field, so that "heavy current" engineering appeared likely to swamp all other applications. Actually, immense strides were made in both branches, and it will be one of my objects to indicate how closely allied are those branches.

The dynamo was responsible for the growth of supply for lighting and power as a d.c. application, and electric tramways were installed everywhere; I recently heard a tramway engineer lamenting the decrease in popularity of the tram and looking back to the days when the tramway load, instead of being a minute fraction of the station output, was competed for and welcomed. Alternating-current machines were then manufactured and for generation and transmission a new era opened—final distribution still being carried out by direct current. This was probably owing to the need for supplying the existing d.c. networks and in order to provide new machines to run in parallel with existing d.c. generators. During this period the "light current" engineers had been very busy, and an immense amount of detail improvement had been made to telegraph and telephone apparatus. Secondary batteries (making use of the dynamo) were found invaluable in this connection.

Cables and jointing were dealt with largely by methods which could be regarded as "rule of thumb," compared with modern practice.

To explain many failures which could not be accounted for otherwise, the ubiquitous word "surge" came into use. To-day, the production of and method of dealing with surges are much better understood. "Lightning" is another convenient peg on which to hang the blame.

I am not suggesting that surges and lightning do not cause an immense amount of trouble—they do—but in many cases it is because they have found the weak spots which only required the pressure to rise a little above the normal in order to cause a breakdown.

CO-OPERATION.

It is more than ever necessary for all branches of the industry to co-operate and to exchange freely information leading to solutions of the many problems still before us, problems which are recurrent and new problems which increase in importance as the undertakings become larger.

Let us consider how this co-operation—co-ordination, call it what you will—may be improved. The quoting of platitudes is easy, but it is necessary at times to repeat them until listeners take notice. Just as the showman and the advertising agent have realized that reiteration of their claims brings a hearing, so, I think, must we remind ourselves of the need for real co-operation in order to increase the usefulness of our Institution and industry.

I should like to give one or two instances where co-operation might be improved.

It is not easy to bring together the right people for discussion when problems involving important technical issues are raised.

Co-operation between Manufacturers and Users.

In addition to such co-operation as may be obtained in meetings such as those of the British Standards Institution, much may be done by representatives of the two sides meeting informally. It will be conceded that a designer's problem is threefold:—

(1) He must be aware of the exact requirements.

(2) He must be able to produce a design which satisfies (1) technically.

(3) He must be able to produce a design which satisfies his own firm that a reasonable profit is obtainable at a price the user is able to pay.

Often is it the case that the only contact is between the manufacturer's salesmen and the user's buyer. This is correct in the first instance, but it would be much better in the long run if the technical staffs were brought together for discussion in the earliest stages.

What is the usual method of dealing with new apparatus or developments? Frequently, the manufacturer originates an idea and proceeds to develop it on the lines he thinks best. In the smaller firms the

principal is directly interested in the scheme and will follow it through all development stages, even taking an active part in the production of the models. He is able to appreciate the shortcomings of the proposals, and will directly modify the models as they are made.

Larger firms must necessarily delegate the developments to special development departments, who will produce and test models until they are satisfied that the proposed arrangements will work. They may have the co-operation of the inventor, or they may have to build up the whole structure having only the bare principle to guide them.

When the development people have produced what they regard as a good technical article, it is the turn of the production departments (and I use this term in its widest sense) to design an article which will incorporate the principles aimed at. It must be durable, of good appearance, and easy to manufacture in any required quantity. The people responsible for selling such an article will have to say what kind of reception it may have and whether the price at which it may be sold will be acceptable. During this time the whole of the development may be kept secret, largely through fear of the action of competitors. Guarded mention of the scheme may have been made to one or two people outside the organization, but only on condition that they did not divulge anything. In the main, the prospective users, who might be expected to know most about the application of the device, will not have been consulted. I suggest that this is quite wrong and that much help might be given by proper co-operation.

As the user is in the best position to know what is required, he will state the problem as he sees it, and the designer will then say how far it is practicable to make an article fulfilling the conditions. It may be found that with a little modification or easing of the user's views, a really satisfactory solution will be obtained. It is really worse than useless for the user to make an elaborate specification unless it is commercially practicable to meet it; neither is it of any value for the designer to put forward a design, however near to perfection, unless there is a demand for it. Frequently, the user will indicate the leading points in the design, and the specialist will shape this and produce an article suited to both. Personally, I have found such discussions most useful, but I had great difficulty at first in getting into touch with the people actually responsible for the design.

Co-operation Within the Institution.

Co-operation of the type I have just mentioned only covers a narrow field and takes place when definite purchases have to be made. There is, however, a much wider field open to us all—I refer to this Institution to which we belong; perhaps it would be better to say which belongs to us, or, better still, to quote the words of a Past-President, who said to the members "You are the Institution."

Unfortunately, many members cannot attend owing to other duties, but others are disinclined to come to meetings unless the title of the paper is particularly attractive, or the subject is one which concerns their daily work. This, I think, is a great mistake, and I am sure it is the experience of most people that many lectures are given in which interesting points are raised and answered in the discussions. To take a simple example, a paper on automatic telephony would cover practically all the points arising in supervisory control of switchgear, although the titles may not show any connection.

Co-operation in the Preparation of British Standard Specifications.

Greater co-operation is needed in connection with the publications of the British Standards Institution, for there is still too great a tendency for these publications to represent the agreed views of the manufacturers. Whilst the views of the users are canvassed through their respective trade and technical organizations, there is still a volume of user opinion which is not sufficiently ventilated. Although there are a few users on the B.S.I. Committees, unless something is done to co-ordinate the general views of users the corresponding work done by the manufacturers must tend to carry greater weight. As a result, many users cannot specify the British Standards without qualification or addition; this reduces the value of publications which have required the expenditure of much time and thought.

It is understood that copies of all draft specifications prepared by the B.S.I. are placed at the disposal of users through their associations, but perhaps more discrimination is required to ensure that these drafts reach the right people. Take, as an example, the British Standard Specification for Outdoor Insulators. It is doubtful whether any undertaking in this country would feel justified in adopting the recommendations exactly as set out, but it would invariably have to select an insulator having a higher flash-over value than those indicated in B.S.S. 137. It is true that there is a table giving the highest working voltages for certain insulators, but this is scarcely an improvement on the older method of drawing up a table wherein a specific recommendation as to size was made.

Another example is the recent draft transformer specification, of which quite large users have little knowledge except for short paragraphs in the electrical Press.

I would suggest that the B.S.I. consider the wider use of direct questionnaires, unless the organizations representing the users can secure adequate discussions of the draft specifications submitted to them and can arrange to submit their views effectively and to see that these views are supported by the attendance of representatives who are qualified to discuss the particular subject under consideration.

Co-operation Between Light-Current and Heavy-Current Engineers.

For a number of years telephone engineering and power engineering were quite distinct. I remember reading in the *National Telephone Journal* a report of a conversation between a telephone engineer and a power engineer. The latter was supposed to have asked what was the telephone man's occupation, and, on being told, said "I didn't think there was any engineering in telephone work." I mention this to show the line which

at one time was drawn between the two branches. I think a broad division might be made by saying that the telephone engineer deals with small movements such as are made by relays, whilst the power engineer deals with much larger movements such as are made by motors; or, even more concisely, one deals with attracted armatures and the other with rotating parts.

From the use of simplest forms of relays there has been immense development and, as usual, many competing systems. One system depends entirely on the use of simple relays having two positions per relay only, whilst another system uses a relay which can move in two directions and so make contact with any one of 200 or more sets of contacts. Both of these systems use successive movements of an attracted armature or armatures, and the latter has become practically standard in this country. Many of the earlier systems made use of power-driven mechanism in the exchanges, some with continuously driven shafts which, by means of magnetic clutches, brought into position the appropriate telephone switches. It is probably true to say that one or other system will develop for reasons other than technical merit—standardization, for instance. In any event, it is true that there has not been much development of the power-driven system in this country; there is, however, a new development of power-driven systems whereby certain apparatus previously moved by the intermittent action of an attracted armature will be motor-operated and will give much higher operating speeds. This will reduce the overall time of use of exchange apparatus, and will enable greater use to be made of the " diversity factor."

" Automatic telephone apparatus " may now be regarded as an integral part of many power schemes, and such " supervisory " systems are proving most useful in connection with the many unattended substations now in use. Both power-driven and non-power-driven systems are in use, and both have proved satisfactory. One fundamental difference between automatic telephony and supervisory control is the need for additional checking back of the set-up circuits in the latter system, as, although failure to operate is bad, it would be infinitely worse to have the wrong switches operate. For this reason it is preferable to have the required circuit set up and to leave the final operation to be a single control—in some cases it may be necessary even to cancel the setting without having made the final operation.

Another valuable development is the use of " voice-frequency " currents to give selective operation or indication over longer lines than can be readily dealt with by ordinary supervisory systems.

Here, as in other instances, much good was obtained by each group of engineers taking note of the views of the other group.

Progress in the Electrical Industry.

What is the future of our industry? There are many conflicting views, and it is not easy to obtain a clear picture.

The returns of authorized undertakers give us a promising record of progress, a yearly increase of output between 10 and 20 per cent being common. Such increase is satisfactory, not only to the supply engineers but also to makers of all classes of apparatus. A study of the advertisement pages in newspapers and other periodicals will show how popular is the demand for current-consuming apparatus. How does this affect the manufacturer?

The first advantage is the demand for the apparatus itself. British manufacturers have made great strides in producing serviceable and ornamental fires, toasters, wireless sets, and many other articles. Electric power is needed to produce these articles, and, again, they take a supply for their operation. This calls, in time, for larger service cables and larger and more transformers and substations, all of which bring greater calls on the manufacturers. Substations, in turn, require additional main feeders, and frequently higher voltages. This brings us back to the power station, whether the supply is taken direct or through the grid.

During the last few years the makers of generating plant have been pessimistic, and not without reason. Probably the comparison between their activity during the early post-war period and that of more recent times has made the latter years seem unduly slack, but a much greater spirit of optimism is now observable.

It is gratifying to note that many schemes for installation of new boilers, turbines, and generators, are progressing, but even now it seems probable that the demand will exceed the available supply. During a recent cold period there were many instances of a demand over 10 times the normal. Since that time many heaters and cookers have been installed, and the next cold period may find a shortage of plant unless large extensions are made to most stations. During normal times the diversity of load enables the supply apparatus to be progressively reduced in size from the final consumer's apparatus to the generating plant.

The rating of the installed apparatus may be 6 to 10 times the generating-plant rating, and this may be satisfactory during normal times. When the heating demand is great this ratio may have to be reduced and greater care will be necessary in deciding the "diversity factor" in future.

Although the costs of generation are now very low, continual attempts are made to reduce them, and one of the most recent methods is the use of high-voltage alternators.

From time to time a halt is called to the increase in generating voltages. For many years 6 600 volts was considered to be as high as was prudent, although 11 000 volts was considered to be quite safe by many engineers. Many machines were built, and are still running, at the higher value, and many miles of 11 000-volt lines and cables were brought into use. Transmission voltages of 33 kV became common, but this needed special transformers in individual feeders, or common to a number of feeders. In most instances this needed special switchgear, and the next step was the elimination of the lower-voltage switchgear and the use of alternator and transformer together to form a composite generating unit. A number of stations were equipped in this way, and the following advantages were obtained:—

The 11-kV switchgear was eliminated, and switching

took place on the higher-voltage side of the transformer. The impedance of alternator and transformer together (approximately 25 per cent) reduced the burden on the switchgear and simplified operation. The two could have common protection, and the transformer relieved the generator of shock due to short-circuit. As the transformer was excited only while the machine was running, and as the latter only ran at high loadings, the proportionate losses were small. Even so, if these losses could be cut out the value of the saving would be considerable.

Valuable experience having now been gained in the use of insulating materials which were practically indestructible, another step higher was made. Pure mica insulation, if very carefully applied to the conductors so as to exclude all air, has a very high breakdown value, so that a pressure of 33 kV was considered to be quite safe for the direct winding of alternators. One very successful design makes use of triple-concentric conductors insulated with pure mica, so that the maximum stress between adjacent conductors is less than 7 000 volts; this stress is radial and the possibility of failure in this direction is small. Against this has to be set the fact that all heat from the centre conductor has to pass through the inner and outer conductors and their insulation. By making the centre conductor larger than the others, it is hoped, however, that no trouble will be experienced. Such machines have been in service for 6 years.

Another school of designers makes use of designs with conductors wound and insulated on standard lines, maintaining that the simplicity of this winding compensates for the increased stress in the insulation (19 000 volts to earth as a maximum). One such machine has been in satisfactory use for nearly a year, and others are being manufactured.

Outputs and steam pressures are also rising.

Protection.

Notwithstanding a wealth of invention, protection has become fairly well standardized for the moment.

For single feeders, fuses or circuit breakers with overload and earth-leakage features are installed; for feeders in parallel, similar protection is adopted at the outgoing end and directional protection at the remote end.

For generators and transformers, circulating-current protection having relays with short time-lags, or with inertia devices, is employed.

For cables pilot-wire protection, either opposed-voltage or circulating-current, is used; whilst for important overhead lines some form of "distance" protection, wherein the operation of the relays is governed by the impedance (or the reactance in some cases) of the line to the fault, is chosen.

Experience has shown that the basic assumption underlying the use of Merz–Price gear, viz. that the input to a section is equal to the output from it, is not strictly correct when there is no fault in the section. Actually, if a fault appears at any point outside the section, the voltage may be lowered to such an extent that there is a discharge from one or both ends of the protected section, whether it be a feeder, a generator, or a transformer.

When the faulty section has been switched out by its own protective gear, there follows a momentary charging current into the healthy sections. In some instances this is sufficient to operate the protective gear, and to avoid such wrong operation some restraint must be used. This is frequently obtained by using relays having a definite "bias"; alternatively, an induction relay with very short delay is used. This delay is practically non-existent when a fault appears in the section.

Importance of Load Factor.

The importance of load factor is not confined to electricity supply; all classes of business are affected. Dozens of schemes have been evolved to improve the load factor, and in most cases they have consisted of special offers to consumers to take "off-peak" supplies. This has introduced the difficulty that "valleys" in the load curve may then become "peaks," as it is not always practicable to adjust the load to fine limits. I suggest that, instead of troubling unduly about the present peaks, efforts be made to obtain new load having nearly 100 per cent load factor. In a very few years the load curve would then have such large ordinates that the present peaks would be scarcely noticeable.

In this connection I think the following conclusions, which are based on the statistics of supply undertakings, will be interesting.

The total load connected at the end of the year 1933 was double that which was connected at the end of 1928. The maximum demand in 1928 was 50 per cent of the connected load, whereas in 1933 it was only 30 per cent of the connected load. The peaks have thus been flattened considerably, and the diversity factor has been more helpful.

From one aspect this is useful, but a more helpful consideration is in connection with the relation between the maximum demand and the average demand, i.e. the running load factor.

It can be shown quite readily that straightforward additions of 100-per-cent-load-factor supplies considerably improve the overall load factor; and if the additions of plant are maintained—and there is every reason to suppose that they will be—the load factor will be automatically improved.

It is becoming a commonplace to recommend the installation of water-heating loads. These are recommended particularly for domestic use in rural areas, where the maintenance of a high load factor makes the fullest use of all the plant right back to the power station.

It is often possible to raise the station load-factor without improving it on individual circuits, but any scheme which will do this and at the same time improve the load factor on the smaller circuits is to be recommended. In this connection it should be noted that the capital costs for distribution are twice those for generation.

Recent Developments.

I have mentioned already the latest developments in generating-plant, e.g. the use of direct-wound 33-kV alternators, and I have touched briefly on protective

systems; I should like now to deal with a number of other detailed improvements.

Routine Testing.

Practically all supply undertakings have some department for the routine testing of supply meters and protective gear. In some cases where the size of the undertaking is small, this testing work forms a branch of one department's work; but the larger undertakings have found it necessary to have a special department controlled by a specialist.

While ordinary household meters can be tested on the bench and then installed without impairing their accuracy, it is much better in the case of large supplies to repeat the tests on site, in view of the many factors which may influence the accuracy of the meters.

It is always more convincing to a consumer to see his meters tested *in situ*, especially if the metering circuit can be tested as a whole. Such testing is facilitated by using current transformers having additional primary windings for testing purposes, and it may, when necessary, be carried out without cutting off the consumer's supply, provided short-circuiting and disconnecting isolators are incorporated.

Transformers.

The transformer which at one time was such a weak link in supply circuits has been so developed that it is one of the safest pieces of apparatus we have. It is rare to find transformers collapsing through short-circuits, and equally rare, in this country at least, to find transformers failing through breakdowns between turns.

The realization that flux densities were tending to become too high has brought improvement by reducing the magnetizing currents, the noise, and the production of undesirable frequencies.

This last-mentioned point is of first importance where long cables are used, and particularly where it is intended to use static condensers for power-factor correction. It has a bearing also on the satisfactory running of rotary convertors.

Domestic Apparatus.

It is disappointing to examine some of the domestic apparatus at present offered for sale, and it is not always the smaller firms who are the chief offenders.

The best apparatus is supplied by medium-sized firms who are specializing in such apparatus, but some of the apparatus offered can have received consideration from one aspect only, namely low price.

As an instance, the ordinary double-pole switch for house-service work may be cited. Faults, such as the use of too small contacts, too little insulation, and tiny earthing terminals, are all too common. Lampholders made of too brittle material and with poor contacts are offered; tracking between terminals has taken place in a number of instances, and the anchoring of the flexible cord is still very often unsatisfactory.

These are just a few instances indicating the need for further technical co-operation between users and manufacturers.

Conclusion.

In conclusion, I would summarize the foregoing remarks as follows:—

(1) Increased co-operation between various branches of our industry in technical matters is urgently needed.

(2) This may be obtained by taking a live interest in our Institution.

(3) Discussions between the technical staffs of manufacturers and users will solve many of the problems which face the two sides.

(4) An expert will remain such only if he is allowed the fullest access to the results of the work he has initiated.

(5) A little prophecy may not be out of place, viz. that within a very few years the heavy-plant manufacturers will be busy; in fact, the promise of growth of load is such that there is a danger of a shortage of generating plant.

NORTH-EASTERN CENTRE: CHAIRMAN'S ADDRESS

By L. E. Mold, Member.

"IN THE WAKE OF THE GRID."

(Address delivered at Newcastle, *22nd October*, 1934.)

Utilization of Electricity.

The British grid is now well established, and the many engineers who have been party to its design, construction, and organization, are to be congratulated upon their great achievements. Members of this Centre have played no mean part in its development, and the house of glass on our riverside is a fine example of engineering in all its branches. Despite the many criticisms of journalists and others, the minor teething troubles in commissioning have been quickly and effectively overcome so that we can now say that the grid is with us.

After these accomplishments we are faced with the task of the full and proper utilization of the facilities available in electricity supply. This task is no easy one and covers many fields of development, amongst which are improved methods of distribution and the development of load in all possible ways.

The subject of distribution is receiving careful attention, and load development is a responsibility which must be shared by all sections of our industry. The supply authorities cannot be expected to do all the work, and the manufacturer must continue his efforts to provide load-consuming devices which will be attractive to the consumer and will save him expense. There is much scope for economy in the sale of domestic appliances, particularly the larger kinds, since in many cases the cost of manufacture is low but the price to the user is inordinately high on account of cumbersome selling methods.

It is interesting to refer to the predictions of Mr. B. H. Leeson, who was our Chairman in 1930 and who gave us in his address an analysis of electricity supply and demand for the period 1910 to 1928 and foretold developments which might reasonably be expected during the period 1928 to 1950. It is remarkable how his curves representing output and coal consumption have been followed during the past four years.

In 1932 the units generated and sold were forecast as 12½ thousand million, and the actual number proved to be 12¼ thousand million. The transport load has not gone up as was expected, and the use of imported petrol has temporarily increased, but the trackless trolley-bus is rapidly developing and is providing a stimulus to the traction load.

Traffic congestion in our towns is increasing to such an extent that tramcars are becoming very unpopular, but the petrol bus must not be allowed to displace them. The electrically propelled vehicle has so many popular claims, such as cleanliness, absence of smell, and comfort in smooth running, in addition to its many operating advantages, that its adoption in Great Britain should be assured. Railway traction is increasing very slowly, but if we follow the precepts of Sweden our total load will correspond to the predicted curve, and a large number of our unemployed will be given work, leading to assured returns on capital expenditure.

The development of water-heating is progressing rapidly and a large potential demand for power seems within reach through the advent of the electrode water-heater and steam-raiser, particularly when applied on off-peak load periods for heat-storage. A number of installations are in successful service, and each satisfied user will produce other consumers. Conversely, a dissatisfied user can do a great deal of harm, and it is bad policy to persuade a consumer to use equipment which may be likely to prove uneconomical or difficult to maintain in regular order. Under proper conditions capital costs, interest charges, depreciation, and maintenance, are all on a competitive basis with those involved by other sources of supply.

The electrode heaters themselves and their associated automatic control gear comprise well-standardized equipment, and considerable economy can be effected in selecting substation sites for such services having regard to projected buildings, so that capital charges for cables, transformers, and switchgear, can be distributed according to the prospective heating demand. Architects are now appreciating the economy in building construction that arrives from the efficient application of electrical means for warming buildings and for providing supplies of hot water.

It is important to refer to the rapid development of this utilization of electrical power in Canada, where the steam-raisers in use have a total installation capacity of 1¼ million kW and are capable of consuming 900 million kWh per annum if used to their full capacity. If the available boiler plant in Great Britain is operated at its maximum efficiency as determined by load factor, it is possible to develop a large night load with little addition to present generation or distribution costs by taking into account the true cost of banking boilers and other losses during off-peak periods.

Other means of utilization of available surplus power during the night are being developed in such forms as annealing furnaces and large drying ovens, and in steam generation for process work.

One of the lessons to be learnt from the gas industry in regard to load development is initiative in service. A gas-pipe is laid to every house which is being built within the area of supply, and the gas companies appear to consider it their right to do so, irrespective of the wishes of the house-owner. It would be interesting to

compare the costs as between gas and electricity of giving such service to a housing scheme.

There is much scope for electric welding and, although the kW demand is not often large from individual consumers, there is a large total demand. Small portable a.c.-d.c. motor-generator sets are available, having special characteristics adapted to give easy welding, and fine current regulation. The average current range is from 25 to 250 amperes for a single operator, and two such sets can be operated in parallel for use with heavy-current electrodes. The a.c. welding transformer is not all that is to be desired as a load on account of the unbalance it causes in giving a single-phase supply from a 3-phase system, and also on account of its low power factor. Further, a d.c. arc has many advantages in respect of stability and ease of control.

Compressed gases are no longer essential for welding, and the transportation of heavy cylinders can be avoided. Remarkable development in ship construction by electric welding, using d.c. single-operator and multi-operator sets, has been effected during the past year or two.

Developments in Switching.

The majority of the C.E.B. secondary transmission lines at 66 kV are controlled by open-type switchgear, but it is gratifying to find that the principle of metal-cladding has been applied to London and the N.E. England area. The former can show examples at Stepney and Bankside, and the latter has substations at Harton, Sunderland, and Hebburn. These are fed from Dunston power station, where switchgear of the same design is installed, and so once more the N.E. Coast has pioneered new designs which have proved satisfactory in service; these are the first 66-kV completely metal-clad equipments to be commissioned. The example emanating from this district of using metal-clad switchgear for power stations on 66-kV service has been followed in the London area at the Battersea power station, and at the Fulham station, which is now in course of construction.

The cable manufacturers are to be congratulated upon the successful development of very-high-voltage cables which are so necessary to the proper continuation of metal-cladding.

Considerable novelty in switchgear design, particularly for use with voltages of 33 kV and above, is being displayed to meet the requirements of economy and ease in maintenance. Such units are inherently large, and it is frequently too costly in the initial stages of development to provide alternate feeds, so that when it is required to carry out maintenance work on those parts of the gear which cannot be completely isolated it becomes necessary to shut down the supply to enable the work to be done in safety. This difficulty has become so very pronounced that efforts have been made to find ways and means of gaining access to any part of the equipment of a particular circuit without interference with adjacent circuits or busbar connections. One solution has been found in constructing the busbars in the form of a closed ring with section isolators so disposed and interlocked that all the apparatus associated with any circuit, including the busbar section, may be completely isolated and solidly earthed. This construction may be described as a "detachable bus-section panel-unit."

The "mesh" connection of busbars has also been adopted, but, though it may be possible to economize in circuit breakers, the interchange of protective-gear connections is complicated when the ring is opened, since two circuit breakers operate in clearing a fault on a circuit. The detachable bus-section panel-unit has all the advantages of the mesh scheme, without involving so many operating complications.

Experience in the working of the grid has indicated that in certain circumstances difficulties may arise in restoring supplies quickly, particularly through delays in synchronizing separate systems following a shutdown. The use of automatic synchronizing, which is now well proved in service, is worthy of consideration. Two systems not normally operated in parallel can be kept in synchronism automatically so that any switching operation which may inadvertently cause paralleling will not do any harm. Similarly two or more systems can readily be paralleled by automatic means if pilot wires are available between the generating stations feeding the systems. Such a scheme can also be used in the control of power station auxiliaries, which may be fed either from the station busbars or from other sources not normally operated in parallel. By automatically maintaining the supplies in synchronism any change-over can be made without risk through paralleling.

So many pleas have been made for the standardization of supplies and service equipment that further reference may seem redundant, but distribution and service costs can only be reduced by steady pursuance of this ideal.

A multitude of switchgear designs are being marketed for substation service at 11 kV and below. Many recent designs ignore the essential factors of security in service, and it is regrettable to witness the return of air-insulated equipment in place of solid compound- or oil-filled gear. For over 20 years the industry has been steadily improving its standards in insulation durability. It must be remembered that insulation is in service all the time, and so it is false economy to sacrifice security in service for small savings in primary cost.

The establishment of the grid has encouraged development in voltage-control devices which enable copper to be more efficiently used and also bring benefits to the consumer. According to the Electricity Commissioners' Regulations the permissible voltage variation at the consumer's terminals is now increased from ± 4 per cent to ± 6 per cent, but it is hoped that this latitude in voltage regulation will not limit the use of improved methods of voltage control. A method of control has been developed in America whereby voltage compensation for sudden loading is so rapid that lamp flicker is eliminated. This is done by means of a booster transformer of special construction with thyratron control.

Electricity in Mines.

Appreciable progress is being made in the mining industry in the general application of electricity to coal-getting, handling, and transportation to the surface, and to the control of the apparatus involved. Fortunately, the Regulations governing the use of electricity under-

ground are such that a high standard of design of all equipment is necessary to ensure the required safety in operation. Protective devices utilizing complete earthing of all metal enclosures are obligatory, and faulty equipment is immediately isolated.

The aggregate horse-power of electrically driven plant in mines in Great Britain increased from 500 000 in 1912 to nearly 2 million in 1932, and I think it would be safe to give the total to-day as over 2 million horse-power.

About 66 per cent of the total power supply to collieries in Great Britain is generated by colliery plants, and the remainder by supply authorities, so that there is hope for load development in this field.

The supply below ground is mainly for pumping and haulage, but during the past few years the use of portable machinery has been rapidly increasing, especially for coal-getting and loading.

In Northumberland and Durham 125 million tons of water are raised annually by electric pumps connected to the power supply systems. This is equivalent to the contents of a lake over 50 square miles in area and 3 feet in depth.

There is much scope yet for electric haulage underground, seeing that there are still 40 000 ponies engaged in this service, as against a total of 64 000 ten years ago.

The number of fatal accidents in mines attributable to the use of electricity is amazingly small when the onerous conditions of service are taken into consideration, and it is safe to say that without the aid of electricity in coal-getting and delivery there would be many more accidents. There has been no increase in the number of fatal accidents due to electricity since 1923, despite the large increase in its use. This achievement has been made possible by the care exercised in the design of equipment and protective devices, and by the effective maintenance of all equipment as required by the Mines Regulations; its example can well be copied in industrial and domestic supplies and services.

Economy by Load Control.

With reference to consumers' installations, I should like to refer to the possibilities of improvement in diversity factor and easement of peak loads by the independent control of heating loads both for room-warming and for water-heating. One system which has been applied in France involves the control of consumers' heating equipment by the supply authority from switching points on the network by superimposing high-frequency impulses on the distributors and providing tuned relays on the consumers' premises which respond to these impulses and, in turn, disconnect the heating load. Similar impulses are applied to reclose the heating switches when conditions of load permit. It may be found that appreciable saving in stand-by generating plant can be effected by this means of control, and tariffs can be adjusted in terms of maximum demand, but the loss of revenue must also be considered. It is claimed that the scheme has great possibilities, but the grid, which is able to meet sudden demands, may lessen the need for extensive application in Great Britain.

Another form of load control, proposed by Mr. G. H. Swingler, Engineer-in-Chief of the Cape Town Corporation Electricity Department, has been introduced to improve the diversity factor of the domestic load on the system as a whole or on any section of it. The load factor of the average consumer's installation is not good, and if water-heating forms part of the load it is expedient to confine it to off-peak periods. By automatically switching the water-heating load in such a way as to level the total load on the installation, the diversity factor of the network is improved without serious inconvenience to consumers, to whom indeed some benefit can be given under the scheme by means of a suitable tariff. This automatic control can readily be accomplished by means of an ingenious bimetal relay.

This method of control permits water-heaters to be automatically connected in service when the normal hand-switched house load falls to a predetermined value, and cuts them out when the load exceeds this value. The ordinary thermostatic control of the heater operates independently of the relay. The scheme is likely to have wide application in the near future, with beneficial results.

Rating and Performance of Circuit Breakers.

The performance and rating of circuit breakers, both old and new, presents an acute problem to-day which is much accentuated in Great Britain since the introduction of the grid.

Despite many publications on the subject during recent years, it is evident that many of us who are intimately concerned are wondering whether any solution is forthcoming that will permit us with ease and simplicity to select circuit breakers adequate for the requirements of a given system, or to assign ratings to existing equipment based on a common or standard specification. It must be admitted that the problem is extremely complex on account of the variance in severity conditions in different test circuits and the many proposals which have been advanced for interpreting performances and the ratings based upon them, and, until recently, the lack of concrete evidence in quantitative proof of such declared ratings.

It is necessary to consider the subject in its broadest aspect, with reference to past history, and to try to arrive at conclusions which meet the conditions of the past, the present, and the future.

A vast amount of information is contained in the paper entitled "Metalclad Switchgear, Automatic Protection, and Remote Control, with particular reference to developments during the last seven years," written by Mr. H. W. Clothier and read by him before this Centre on the 22nd February, 1932.* The discussion and the reply are also most informative, and indicate the many differences of opinion held by competent authorities on vital issues. In his paper Mr. Clothier advanced the first proposals for a standard test circuit.

Thanks to the enterprise of members of this Centre, a large short-circuit test-plant has been available at Hebburn during the past four years, and, in consequence of the facilities it affords, research work and service tests have been carried out on numerous forms of circuit breakers, so that reliable data, previously unavailable,

* See vol. 71, p. 285.

are now to hand, and great advances in the art have been made.

In the early days of circuit-breaker design—say prior to 1906—the question of breaking capacity was hardly recognized, and the chief function of switchgear was to make and break relatively small currents. As the generating-plant capacity of systems increased and generating stations were operated in parallel, it became evident that something more than what would now be described as an oil switch was necessary to deal with the increased fault-currents, and designers tackled the problem in various ways.

The Americans developed the "pot" type of circuit breaker using strong cylindrical metal pots with a relatively small quantity of oil and spring-operated closing mechanism. The circuit breakers gave good service but occupied much space and depended upon air insulation.

Continental practice, and to a large extent British practice, favoured the use of larger volumes of oil in tanks of light structure, longer breaks, and larger air-cushions. Many tanks were burst, with resultant secondary explosions and oil fires.

Developments in this area arising out of experience gained on rapidly growing and interconnected systems were founded upon the use of a strong enclosure of the circuit-breaking parts, coupled with total immersion of all conductors in oil or insulating compound contained in earthed metal housings. This unit design has proved to be the most effective and is now almost universal. It was the origin of the high-gas-pressure circuit breaker.

The whole of the progress in circuit breaking was based upon empirical formulæ evolved from experience gained under operating conditions by collaboration between manufacturers and operation engineers, yet without means of quantitative proof under controlled conditions of test.

In 1923 a British Standard Specification was published by the British Engineering Standards Association (now the British Standards Institution), in an endeavour to establish some standard of performance in circuit breaking, but the lack of testing facilities did not permit manufacturers or users to prove their circuit breakers or to verify the specification. Moreover, the specification did not take into account some of the major factors now known to control the severity that determines the performance of a circuit breaker. The 1923 specification was reissued after revision in 1929, but since there were no test facilities in the country we are now able to appreciate the extent of its incompleteness, and we look forward to a new edition in more complete form embodying conditions of test severity.

It is very desirable that a universal specification should be established which shall clearly define what is meant by kVA when used as a measure of breaking capacity and how it shall be determined, since there is great diversity of opinion, both nationally and internationally, and until methods are universally agreed upon we can have no common basis of rating and performance. To illustrate this point I need only refer to the standard methods used at the Hebburn test plant to record kVA performance values. Tests are made at this plant to meet all international specifications, and eight different methods of interpreting a given performance are used. The values so arrived at only depend upon current and voltage measurements in determining kVA, and do not take into account the other important conditions of severity that affect the stress upon the circuit breaker and to which reference is made later. The eight methods involve combinations of two different values of breaking current and four different values of voltage, all obtained from the same oscillograms, and the difficulty of the manufacturer in tendering to the several requirements of these specifications will be readily appreciated.

The other variables of vital importance, if taken into account in the calculations, would lead to a further and even more bewildering multiplicity of results.

In order to lead up to definitions of the principal variants under discussion, it is perhaps easiest first to enumerate the more important phenomena of circuit-breaking, the fundamental principles of which apply to all forms of circuit breakers.

Upon separation of the contacts of an oil-immersed circuit breaker carrying an alternating current, the resistance between the contacts is greatly increased, with the result that an arc is formed between the contacts. This arc consists of a stream of electrons and ions, which is maintained until the cessation of the current-flow during a half-cycle, following which there is an almost imperceptible pause, termed the zero pause, prior to reversal of current flow in the succeeding half-cycle.

During a zero pause, a path or mist of residual ions remains, which has a variable electric strength commencing at a low value. This path is broken down by the impressed electromotive force in the circuit, which re-establishes the arc-stream during the next half-cycle. As the contacts continue to separate, the electric strength of the residual ionized path increases in proportion to its length and to the rate of de-ionization, until the impressed electromotive force is insufficient to re-establish the arc, and thus it is extinguished. The arc length is largely a function of the circuit voltage.

The heat generated by the arc, which reaches a temperature of the order of 3 000° C., causes dissociation of the oil, and a bubble is formed around the arc-stream, consisting of the gases so produced. Hydrogen, which forms a large proportion of these gases, is a good de-ionizing agent. The rapid expansion of the gas bubble due to the rate of gas generation during each successive half-cycle establishes considerable pressures within the oil, and these are reflected from the tank walls. Provided that the total enclosure is of sufficient strength to withstand such pressures, the relatively cooler gases forming the outer portion of the bubble are injected into the residual arc-path, absorbing the residual ions and thereby increasing the electric strength until extinction occurs. The process is, in effect, a race between the rate-of-recovery of electric strength in the arc path and the rate-of-rise of voltage endeavouring to re-strike the arc. The latter factor is important and is known as the rate-of-rise of re-striking voltage.

This method of accelerating de-ionization is well described as "turbulence," and is the most important factor in the development of circuit-breaker design, the

majority of arc-control devices being dependent upon it for their satisfactory performance. Other factors, such as cooling of the arc-root, potential grading, and lengthening of the residual arc-path by magnetic effect, are of lesser importance, although in some designs one of them may predominate.

The effect of turbulence is emphasized by considering the conditions in a 3-phase single-tank circuit-breaker with two breaks per phase, so that six arc-bubbles are formed with varying rates of gas generation and pressures. The violent movements set up in the oil assist in the rapid de-ionization in each arc path by turbulence.

Turbulence occurs in a plain-break circuit breaker and is most effective when the design is such as to take full advantage of it. To obtain the maximum effect it is necessary to resort to the early principle advanced in this district, namely the use of a strong container with a relatively small air cushion, which construction limits the expansion of the gas bubble owing to the small air cushion volume and at the same time, owing to the strong container, produces the pressure necessary for turbulence. If the bubble is allowed to expand to a greater volume than the air cushion by the use of a weak tank, oil-throwing must occur, and emission of flame is likely.

Many types of contacts have been developed during recent years, operating on the principle of improving the intensity of turbulence. One of these is named the turbulator. Its particular application is at the higher voltages, because with the larger tank dimensions required for insulation and voltage clearances such a contact is a convenient means of utilizing the effects of turbulence. The breaking currents are less at the higher voltages, and the requisite impulse pressures are more easily established in the small container of the turbulator. The turbulator reduces the pressure on the main tank walls, but, notwithstanding this, it is not advisable to weaken the strength of the main enclosure materially.

The stress to which a circuit-breaker enclosure may be subject is due to the impulse pressures established by gas generation during the process of bringing about arc extinction. The rate-of-rise of re-striking voltage is a predominant factor in stress, because when it is high the arc is likely to be re-established for a greater number of half-cycles, with consequent increase in arc energy and gas generation.

The re-striking voltage is a transient phenomenon which appears across the arcing contacts at each zero pause as a high-frequency oscillation due to resonance, according to the inductance and capacitance in the circuit. Its maximum value is mainly controlled by the recovery voltage, the natural frequency of the circuit, the damping effects in the test circuit, and the characteristics of the arc. The recovery voltage varies according to the voltage decrement across the circuit-breaker terminals during a short circuit as determined by the kW capacity and characteristics of the generators in relation to the short-circuit power. This voltage is usually expressed as a percentage of the normal phase voltage, and is measured at the instant of arc extinction in the last phase to clear.

It is apparent that the recovery voltage in service may vary over appreciable limits according to the position of the fault in relation to the generating plant and the circuit breaker, together with the method of earthing employed. On a 3-phase system with an insulated neutral, the recovery voltage on the first phase to clear attains a value 1·5 times as great as the phase voltage of a 3-phase system with an earthed neutral point.

When the recovery voltage is high, i.e. when it is approaching 100 per cent of the normal voltage, the rate-of-rise and amplitude of the re-striking voltage are increased, and this can cause an increase in arc duration, in arc energy, and in the stress upon the circuit breaker. Since the rate-of-rise of re-striking voltage is an important factor in determining the stress in a circuit breaker, a relatively high value of inductance or capacitance in a circuit will reduce the periodicity of oscillation in the circuit, with corresponding reduction in the rate-of-rise of re-striking voltage, and it follows that this will bring about an easement in stress. Conversely, a circuit breaker connected directly to the terminals of an alternator, and so having relatively little inductance or electrostatic capacitance in its connections, may be subjected to more stress when opening on such a short-circuit than it would be when opening on a short-circuit on a network with an equivalent fault-kVA in terms of voltage and breaking current at a point where appreciable inductance and capacitance are inherent in the circuit. It is sufficient to say that, for a given kVA broken, the stresses in a circuit breaker may vary in ratio as much as 3 to 1 according to the circuit characteristics, and the circuit breaker might clear a fault quite satisfactorily under the easier conditions but might be destroyed under the severer conditions.

It is customary to express the ratings of alternators, transformers, and the like, in terms of kVA, and vicinity short-circuit values on a given system are usually stated in similar terms. For the latter, the current is determined from the circuit voltage and impedance as an r.m.s. value under symmetrical conditions. It follows that for logical comparison the breaking-capacity rating of a circuit breaker should be expressed on a similar basis, i.e. as the product of the rated voltage, the r.m.s. symmetrical breaking current, and the appropriate phase factor.

I have already referred to the views of different authorities upon the interpretation of oscillograms obtained from short-circuit tests in determining the values of voltage and current to be used for the purpose of stating a performance or assigning a rating. In some cases the voltage is taken as the rated or test voltage, and in others as the recovery voltage after arc-extinction. The recovery voltage may vary between 150 per cent of normal voltage when measured on the first phase to clear and 75 per cent when measured at the instant of arc extinction, depending upon the characteristics of the test-circuit, and although this may appear to be a large variation its effect is small compared with the possible variation in the rate-of-rise of re-striking voltage owing to the small electrostatic capacitance of a test circuit compared with the large electrostatic capacitance of a network. It is therefore better from the standpoint of standardization to use recovery voltage as one of the functions of severity of the test circuit with reference to

performance, and to assign a rating by calculating the kVA with the rated voltage.

In determining breaking-current values it is usually found that displacement of the alternating current-wave has taken place, and in analysis a new zero-line is obtained by drawing an envelope enclosing the current-peaks so that at any instant the d.c. component can be obtained by measuring the distance between the two zero-lines.

For the purpose of calculation of kVA it is simpler, and in line with normal determination of kVA, to use the a.c. component and to treat the d.c. component as a condition of severity in the same way as recovery voltage. It is not logical to exclude the d.c. component entirely, on account of its effect in circuit-making when peak values have to be taken into consideration, and I will refer to this aspect later.

I have endeavoured to show the advantage of using known values of voltage and current, e.g. the normal voltage and the a.c. component of current, in calculating an assigned kVA, and to deal with the associated variable functions of recovery voltage and d.c. component of the current only as factors of severity in calculating kVA performance. It will be clear that the meaning of a kVA breaking-capacity rating will depend upon the conditions of test severity under which a circuit breaker has been proved, and the method of calculating the assigned rating from such performance.

The power factor of the fault current can have appreciable bearing upon the performance of a circuit breaker and therefore should be treated as one of the factors of severity of the test circuit. At zero power factor the voltage wave will be at its maximum at the instant of zero current, and arc duration may be increased accordingly. However, with a power factor between zero and 0·15 the stress is reasonably constant and slight easement occurs up to a value of 0·3. Easement increases with improvement in power factor up to unity.

As has already been stated, the severity of a test circuit may vary within very wide limits, and it is therefore most important that the conditions of severity should be defined and standardized. A great deal of work has already been done in this district, and a method due to Mr. B. H. Leeson and Mr. J. A. Harle is worthy of our utmost support. The subject is too extensive and complex to be dealt with in detail here, but I hope that we shall have more complete information before the Institution in the future. In the meantime a brief outline may assist in furthering the essential aim of standardization.

The following conditions must be taken into account when proving the performance of a circuit breaker:—

(1) The condition of the circuit breaker for test.
(2) The behaviour of the circuit breaker during test.
(3) The condition of the circuit breaker after test.
(4) Test voltage.
(5) Power factor.
(6) Earthing of the test circuit.
(7) Operating duty.
(8) Recovery voltage.
(9) Frequency.
(10) Severity factor related to re-striking voltage.
(11) D.C.-component multiplier.

The objective in view in preparing a universal specification governing the rating and performance of circuit breakers under short-circuit conditions is to enable comparison in test results to be obtained when the tests are made on plants having different characteristics. In other words, a "test-plant factor," or, more aptly, a "severity factor," is required for each test circuit, preferably one that would permit a working tolerance or range in the recovery voltage and d.c.-component multiplier that could be permitted for a standardized test-circuit severity.

The severity factor of a test circuit can be considered as an arbitrary factor expressed in volts per microsecond calculated as the product of four multipliers, and represents a measure of the inherent severity of a given test circuit at the instant of arc extinction in the first phase to clear. The four multipliers are:—

(1) The equivalent frequency multiplier.
(2) The recovery-voltage multiplier.
(3) The d.c.-component multiplier.
(4) A numerical constant.

The equivalent frequency multiplier is a novel measure of the inductance and capacitance of a test circuit, from which the rate-of-rise of re-striking voltage for any particular value of recovery voltage and d.c. component may be readily calculated. This multiplier is obtained before the test from a cathode-ray oscillogram taken in conjunction with a circuit breaker which is capable of breaking circuit in not more than one half-cycle. The second and third multipliers are available from the oscillograms after a test and can vary considerably according to the kVA test value with respect to the test-plant capacity and characteristics. With this method of calibrating the severity of several test-plants, it is only necessary to establish a standard minimum severity factor with which all test plants must comply.

In general we require to have a common basis of measurement of values of voltage and current, together with a set of standardized conditions of severity that include a severity factor, to enable a proper comparison to be made between test results in performance and ratings assigned from them. This procedure, or its equivalent, is of vital importance to the industry. The Institution can, and should, make every endeavour to secure an early solution of these problems.

These considerations are not based upon purely academic formulæ, but are the results of many years of intensive research with a large test plant, and with the closest possible co-operation between the designer and the user.

So far reference has been made only to breaking capacity, but a more comprehensive term would be "switching capacity," which takes into account "making a circuit." The making-rating defines the ability of a circuit breaker to close when a short-circuit exists on the system, and the term is required because the making-current is not necessarily equal to the breaking-current. The r.m.s. breaking-current must be converted to its equivalent peak value, and under asymmetric conditions this peak current-value is still further increased on account of the displaced current zero and may be taken as 1·8 times the symmetrical peak value or approxi-

mately $2\frac{1}{2}$ times the r.m.s. breaking-current. This factor is important, because the closing mechanism of a circuit breaker must be able to close against a short-circuit in order to provide for opening the circuit properly when the trip mechanism is energized. A weak electrical closing mechanism is likely to prove dangerous, in that the contacts will separate immediately after making contact owing to magnetic repulsion and gas generation, and will then reclose. Similar successive opening and closing operations will follow until the trip mechanism is released; in all probability the tank will burst because of the excessive gas pressure generated. In manually-operated circuit breakers such risks are even greater, and hesitant operation must be avoided. The safe limits for hand operation are of the order of 10 000 peak-amperes, and above this value it is advisable to use mechanical means of closure. A convenient type of mechanism has recently been developed for intermediate ratings, in which a spring is first compressed by a hand lever, and closure of the circuit breaker is effected by releasing a holding-latch by electrical or mechanical means. This mechanism can be made in portable form for use in closing any one of a bank of circuit breakers.

As an alternative, particularly with very large circuit breakers operating on the lower voltages, with making-currents of the order of 200 000 amperes or more, it may be preferable to install a relay protective system such as the " fault lock-out " system, in which pressure from a voltage transformer is applied to the line during switching in such a way that if a short-circuit exists the circuit-breaker trip mechanism is energized and prevents closure.

Many proposals are being made to improve the performance of circuit breakers of the older types by the addition of arc-control devices, and in some cases it is proposed to increase materially the ratings which were assigned to them in earlier days. In considering such proposals it is necessary to give careful attention to the design of the whole structure, the conductors and their supports, the circuit-breaker operating mechanisms, and all ancillary apparatus. Although the normal load current to be carried may not be increased, the straight-through or fault currents will be largely increased, and the effects, both thermal and mechanical, must be carefully examined. Current transformers are often a weak link, and their failure may wreck an equipment. Special arcing contacts can be fitted which may reduce arc energy by speedier arc extinction, but this does not limit the value of the fault current which may flow, nor does it afford any easement in the mechanical forces due to the increased current so carried. It is safe to say that in most cases it is better to replace the old equipment with new switchgear properly rated. Modifications can be made to give improved performance, but too much faith should not be placed upon estimated performance without adequate proof by a short-circuit test on the whole equipment.

It is important that concern for switching capacity, which is only in occasional demand, should not be allowed to overshadow consideration of other functions in judging the merits of a particular circuit-breaker design. It must be remembered that everyday service is required, no matter what may be going on in the circuit.

Insulation security is of paramount importance in assessing the true safety factor in everyday performance, with special reference to continuity of supply. During recent years more care has been taken in the design of insulation for the higher than for the lower voltages, say 11 kV and below, and British Standards need revision.

The German V.D.E. Rules require very high standards, perhaps too high. For example, apparatus for use on 13-kV systems must be tested at 64 kV for 5 minutes, which means that apparatus made to British Standard Specifications for similar service would have to be of 22 kV standard rating to withstand the V.D.E. pressure tests.

Here again I would make a strong plea for international standardization with really safe limits. We should not follow the example set by users in some countries where the next higher standard voltage is specified to ensure an adequate margin of safety at the working voltage. Manufacturers in all countries should be placed in a position enabling them to supply standard apparatus for standard voltages for normal conditions of service. Special provision may be necessary for abnormal circumstances such as severe climatic conditions and high altitude.

In these notes I have alluded to some of the problems that are now before the industry and are associated with present-day conditions of electricity supply, both in this country and abroad. It is difficult to obtain international agreement on many of these controversial questions, but it is gratifying to know that Great Britain is to the fore with constructive proposals, and they must have our full support if standardization in ratings with respect to performance in all services is to be attained.

Apart from these problems we have to pave the way to further development of load and of the grid. I hope I have indicated some ways in which manufacturers can try to take a share in this development. An increase in the co-operation of all concerned will hasten the coming of greater prosperity through increased demand and consequent diminution of unemployment.

NORTH MIDLAND CENTRE: CHAIRMAN'S ADDRESS

By Professor E. L. E. WHEATCROFT, M.A., Member.

"SOME ENGINEERING APPLICATIONS OF ELECTRICAL CONDUCTION THROUGH GASES."

(ABSTRACT *of Address delivered at* LEEDS, *23rd October*, 1934.)

I propose in this Address to call attention to the increasing part which conduction through gases is playing in modern methods of control of electric power, and you will agree that, while the outstanding advantage of electricity over other forms of power is the possibility of transmitting it over comparatively large distances, yet its general usefulness must stand or fall by the ease with which it can be controlled.

Control apparatus falls into three groups:—

(1) Those employing direct opening and closing of a circuit, as in a switch: this, of course, is the oldest method and still forms the basis of most control devices.

(2) Those employing indirect magnetic control as in the induction regulator: I have nothing more here to say about this method. Its present applications are fairly well known.

(3) Those employing indirect "grid" control by valves: this, the youngest method, finds every day new applications and is capable of great things in the future.

It is not possible in anything less than a small book to deal with all modern applications of gaseous conduction, even the most interesting. I shall therefore confine myself to recent trends of development in mercury-vapour rectifiers and in circuit breakers, and even so I shall leave out applications which may well be equally important, such as the air-blast rectifier and gaseous-discharge lighting.*

MERCURY-VAPOUR RECTIFIERS.

The mercury-arc rectifier is an old-established piece of apparatus which increases in popularity as more reliable designs are developed. The constant bogy of the designer is the fear of backfiring (failure of the rectifying action), since this involves a short-circuit of both the a.c. and d.c. systems. By experience and research the conditions tending to cause backfires have slowly been isolated, so that the manufacturers can now claim the necessary reliability in this respect. The resulting design is, however, a compromise between the factors which ensure safety against backfire and other factors tending to greater efficiency or lower costs, with safety the predominating consideration.

It is well known that the rectifier was developed from the mercury-vapour lamp of Cooper Hewitt 30 years ago, and since that time a great deal has been learned about the conduction of electricity through gases. We may therefore well ask why it is that no other gas has been found to succeed mercury vapour. The answer is twofold. If a permanent gas is used in a valve, the accelerated chemical action which always accompanies a heavy discharge "cleans up" the gas so that the pressure is continually reduced; if, therefore, reasonable pressure is to be maintained, a large reservoir of gas would be needed. If, however, we use a vapour in contact with its liquid, a few drops of the liquid are sufficient to form an almost inexhaustible source. We have, however, the disadvantage (if it is a disadvantage) that the vapour pressure now varies rapidly with the temperature. In mercury, for example, the pressure in millimetres of mercury column is as shown in Table 1. A change of temperature from 0° to 100° C. multiplies the pressure by over 1 000, with consequent changes in the characteristics of the vapour conduction.

* See References (7) and (8).

TABLE 1.

Mercury-Vapour Pressures.

Temperature	Pressure, in mm of Hg
°C.	
0	0·0002
20	0·0013
40	0·006
60	0·024
80	0·090
100	0·27

The second part of the answer relates to the cathode. It is often supposed that the rectifying action arises from an inherent difference between the two metals used as cathode and anode. This is not so. The rectifying action arises from the fact that an arc is struck (deliberately in the process of ignition) and maintained on one of the electrodes, and is prevented from forming on the others. In fact, the design features embodied to prevent backfires are simply those which by experience have been found to prevent the formation of a "cathode spot" on these other electrodes. In order to maintain the arc, the current must be continuous at the cathode,* and consequently at least two anodes must be provided so that the current in one may begin before the current in the other has died out.

Now in any arc conduction rapid evaporation of the cathode is a natural phenomenon† and it follows, there-

* A rectifier has recently been designed in which the arc is re-ignited at the beginning of every cycle (see Reference 9).

† Under certain circumstances it can be eliminated or much reduced, as it is in the Marx rectifier and the De-ion circuit breaker.

fore, that a liquid cathode is necessary to continuous running in order that it may reform by condensation of its vapour. This is why mercury is used and why it is not likely to be replaced for this type of rectifier.

The efficiency of the rectifier itself is dependent upon the voltage-drop necessary to maintain the arc. This drop is to a large extent independent of the current, and varies in different designs from 17 to 30 volts. It is made up of two parts—a cathode drop of 10 volts, and an anode and arc-stream drop which depends upon the current density and the arc length. It follows, therefore, that it is not possible in any design to have a total drop of less than 10 volts, and in any practical design, with reasonable freedom from backfires, it is considerably more. The comparative constancy of the drop means first that the efficiency is nearly independent of the loading, and secondly that it is better the higher the voltage on which the rectifier is used. Comparative figures of rectifiers and rotary convertors are shown in Table 2.

TABLE 2.

Comparative Efficiencies of Rectifiers and Rotary Convertors.

	600-volt service			
Load	1/4	1/2	3/4	Full
Rectifier ..	93 %	94 %	94 %	93 %
Convertor ..	88 %	93 %	94 %	94 %
	1 500-volt service			
Load	1/4	1/2	3/4	Full
Rectifier ..	95 %	96 %	97 %	96 %
Convertor ..	86 %	91 %	93 %	94 %

The principles of rating gaseous conduction apparatus are quite different from those applying to electromagnetic machinery. In the latter case the limiting feature is always the temperature (of the insulation as a rule), and since there is naturally an appreciable heat capacity a considerable overload can be sustained for short periods. To put the matter more precisely, a transformer designed for a given continuous rating can be made to carry 50 per cent overload for, say, an hour, without extra initial cost. On the other hand, with a rectifier the momentary load is the main governing factor in the design, since it is the momentary current which determines the liability to backfire. The continuous rating may be set lower than this with some, but not great, saving in cost. Since, therefore, in actual practice a rectifier is always used with a transformer, the latter will naturally set the continuous current limit while the rectifier will set the instantaneous current limit.

Our knowledge of the essential phenomena of the mercury arc is largely due to the work of Gunther-Schulze,* Langmuir and his colleagues,† Compton and his colleagues.‡ In one of these papers (in 1931) Compton remarks, "the entire problem of the mercury arc is concentrated at the cathode, since the work of Langmuir and Mott-Smith, Tonks and Langmuir, Eckart and Compton, and Killian, have essentially explained all other regions of the low-pressure arc." This is true from the point of view of the physicist, but from the designing engineer's point of view little quantitative information has been published. We may perhaps assume that manufacturers have a good many results of researches which they have not thought fit to publish. However, practical papers on backfiring conditions have been published by Slepian and Ludwig,* and Hull and Brown.† Recent improvements have resulted from a realization of the importance of details of manufacture and from experience of the features of design which afford the optimum compromise.

* See Reference (1). † See Reference (2). ‡ See Reference (3).

The sizes attained by modern design are, as far as my information goes, as follows: At low voltage (250 volts) for electrolytic work up to 16 000 amperes have been rectified in one tank. In this country (where this type of electrolytic demand does not exist) a peak load of 12 000 amperes at 600 volts has been attained. In the voltage scale, 30 kV has been claimed: in this country the 20-kV 600-kW rectifier installed at Droitwich broadcasting station represents a peak of achievement. The largest output peak developed is 12 500 kW in one tank at 1 650 volts.

It is, however, possible that the course of rectifier development will not follow the same lines as machinery in tending to larger and larger units. It is claimed by some manufacturers that efficiency is not improved by increasing the size of the unit, since a greater arc length is accompanied by a greater arc drop. It is quite possible to operate rectifiers in parallel, and as a result their present policy is to make up, for large outputs, sets of as many 6 000-ampere units as are required.

The improved efficiency is not, however, noticeable above about 600 volts, and it is likely to be offset by the increased complication of the auxiliary apparatus.

GRID CONTROL.

The principle of controlling the striking point of an arc by means of grids is not new, having been developed for the glass-bulb rectifier many years ago, and for steel-tank rectifiers as long ago as 1921. It has, however, lately received a considerable boost, particularly in the German technical Press. The reasons for this sudden advertisement may be one or all of several. First, there is the increasing reliability of steel-tank rectifiers in recent years, and possibly also the development of glass-bulb rectifiers into what may be called "power" sizes. Secondly, there is the stimulated interest in grid control given by familiarity with the 3-electrode vacuum valve. Thirdly, there is the fact that the grid has been found helpful in protecting the steel-tank rectifier from backfires, and, given the grid, it is natural to connect it to a terminal outside the tank and use it for the purpose of control.

A grid is provided adjacent to each anode and it functions only to hold back, as a result of negative bias, commutation from one anode to the next. As soon as

* See Reference (4). † See Reference (5).

an anode has "picked up" the current, its particular grid is neutralized by a sheath of ions and ceases to exert any control. It only regains control when the current to its particular anode becomes zero as a result of a further commutation.

Even this somewhat limited function, however, has made possible a large number of schemes, many of which make little use of the rectifying property (except as an aid to commutation). As far as I am aware only two have met yet with commercial success, namely arrangements for protection and regulation of rectifiers.

The scheme for protection is simple and effective. In the event of trouble of any predetermined kind, high negative bias is applied to all the grids, so that commutation at once ceases. This, in effect, acts immediately to shut off the flow of power from the a.c. side, so that in the case of a short-circuit on the d.c. side it will clear the rectifier more rapidly than the high-speed d.c. breaker. In the case of a backfire, which is in effect an internal short-circuit in the rectifier, grid arc suppression is still of value in limiting the reverse action to one anode only, so that the power fed from the a.c. side is suppressed; the power fed into the rectifier from the d.c. side must in this case, however, be cleared by the d.c. breaker.

It must not be supposed from this that grid-controlled rectifiers will normally supersede circuit breakers as protective apparatus. A circuit breaker is essentially an emergency piece of apparatus acting only on rare occasions; it is therefore uneconomical to tolerate any appreciable losses under normal conditions—even 99·9 per cent efficiency would be too low. It is just this fact which makes it difficult to introduce any radical alteration in circuit-breaker principles: under normal conditions there must be a closed metallic circuit which is rapidly changed for gaseous conduction when emergency arises.

Regulation by grid control is achieved by delayed commutation, and acts in the same way as shifting the brushes in a mechanical commutator. Thus the resultant mean d.c. voltage is proportional to cos α, where α is the angle of delay. Assuming the direct current taken (and consequently the alternating current supplied) to remain the same, the reduced voltage entails reduced power output: therefore the reduction must be accompanied by a lower power factor on the a.c. side.

The grids may be excited by sinusoidal alternating voltage superposed on a negative direct biasing voltage. By adjustment of phase or amplitude, the instant when the grid becomes sufficiently positive to fire the anode can be regulated. This method is simple, but not so good as that where a sudden positive impulsive voltage is applied, since by sudden application the instant of firing is better under control. The peaky wave-form is achieved by a saturated-core transformer.

Invertors.

If commutation is delayed by 90° the mean d.c. voltage is zero, and the a.c. power factor also zero. If the delay be still more, the "rectifier" will only work if the d.c. voltage changes sign. In other words, power is now drawn from the d.c. side and the rectifier becomes an invertor. At the same time power is supplied to the a.c. side at a *leading* power factor, so that there must be synchronous machinery large enough not only to supply the magnetizing current to the a.c. load, but also to provide the commutation voltage of the rectifier. This may be an important factor in deciding the economy of supplying a.c. systems from d.c. transmission lines. For example, with a general system load of 70 per cent power factor lagging, the kVA rating of the synchronous condensers must be nearly 1½ times the kW supplied to the system by the invertor.

The transition from rectification to inversion takes place by a reversal of voltage polarity on the d.c. side, since the current can only flow in the rectifier from anode to cathode. Since this reversal is normally intolerable, in cases where power flow in either direction must be catered for, it is necessary either to provide a reversing switch on the d.c. side (obviously an unsatisfactory solution) or to provide duplicate apparatus, one to rectify, one to invert. In this respect the arc rectifier is at a disadvantage in comparison with synchronous mechanical commutators (of whatever form) where current flow can easily take place in either direction, since there is direct metallic contact during the conduction periods. The Marx rectifier appears also to have the same advantage as the mechanical rectifiers.

Hot-cathode Rectifiers.

The development of this type of rectifier has followed a different course, having grown out of the vacuum electron valve such as is used for radio. For the reasons given above, vapour is commonly used in place of a permanent gas, although in some applications where consistency of characteristics is essential, the use of argon, neon, or inert gas mixtures, is being developed. Up to the present, mercury vapour has been used almost exclusively; this is possibly due to the fact that its characteristics are already well known and its suitability well established, rather than to any merit over all other possible rivals. Thus development has been pushed on in the direction of increased sizes and greater reliability rather than in exploring other gases for other characteristics. It is possible that application may be found for sodium or other vapours which ionize more easily than mercury.

It is not yet clear how the field of applications will ultimately be divided between the mercury-pool cathode and the hot-cathode rectifier. Present commercial sizes obtained in the latter are up to 75 amperes (mean) at 15 000 volts and 100 amperes (mean) at 1 500 volts. The peak current-rating for this type of valve is about 6 times the mean. Perhaps the best way of considering its relation to the other types is to enumerate its advantages and disadvantages. Compared with the steel-tank rectifier it is a sealed valve requiring no pumping system, but compared with both types of mercury-pool rectifier the current is limited by the cathode emission to a density much lower than that which the liquid cathodes will stand. On the other hand, compared with the pool rectifier it requires no striking mechanism and the arc need not be maintained by a polyphase system of anodes. It is, therefore, perhaps more suitable for high-voltage applications where condenser smoothing is cheaper than choke smoothing and where the current is necessarily intermittent at low loads. Finally, many

interesting circuit connections are possible if single valves each with one anode and one cathode can be connected in series: this is obviously not possible in a rectifier where there are two anodes to each cathode.*

Grid control, is, of course, as much, or more, a feature of these rectifiers as of the others, and in fact many of the interesting applications of single valves as sensitive relays and the like are only possible where there is a hot cathode, or at any rate where the arc is maintained by auxiliary means.

Circuit Breakers.

Compared with the rectifier the circuit breaker has a difficult task. Since it is only used for protection, its losses in normal operation must be negligibly small, while the current which it must handle in interrupting a short-circuit will be 20 or 30 times as great as that of the rectifier.

Qualitatively its action is the same as that of the rectifier; quantitatively its task is much more difficult. On the other hand, when it interrupts the current it does so once for all, whereas the rectifier must act continuously 50 times a second.

As has been pointed out by Slepian, the interruption must be accompanied by an arc, in which, unfortunately, a large quantity of energy is liberated as heat in a short time. The amazing thing, therefore, is that it has been found advantageous to immerse that arc in an inflammable liquid. There is no doubt that oil is a potential source of trouble, but Roth† says, "the danger with modern design of circuit breakers is in practice limited to the cases where the guaranteed rupturing capacity is exceeded or where there is defective material or maintenance." This faith must be attributed to the installation during the last decade of testing plants of adequate size: in America there are now in existence plants of 600 000 kVA short-circuit capacity, and in Europe and in this country more than a million kVA.

In spite of this it cannot be said yet that we fully understand the action of the oil. Being liquid, it acts both to cool and compress (or confine) the arc when interrupting, and also (in distinction from other possible liquids) it has a high electric strength under normal conditions.

Following upon the installation of adequate testing sets and as a result of the policy of interconnection which was adopted by utility companies during the same period, many modifications were made in attempts to increase the interrupting capacity of the oil circuit-breakers. These included (*a*) multiple breaks, (*b*) heavier tanks, and (*c*) internal explosion pots.

Fig. 1 shows the principle of the explosion pot. The arc is drawn in the interior of the pot by the downward movement of the lower contact, and the energy put into the arc in the first half-cycles causes a rapid rise of pressure which tends to force the liquid out. As soon, therefore, as the lower contact rod is clear of the mouth of the pot there is a rush of liquid oil into the path of the arc, removing the ionized vapour and substituting the dielectric liquid. As a result the arc fails to re-establish itself in the reverse direction after a zero point of the current wave. The scavenging action is greater, the higher the current being interrupted.

The recent search for new principles of interruption has resulted in designs which may be classified as follows:—

(1) Scavenging by movement of the surrounding fluid, using (*a*) oil, (*b*) water, and (*c*) air.

(2) Scavenging by movement of the arc.

(3) Arc subdivision.

Methods (1)(*b*) and (1)(*c*) are the results of attempts to get away from the inflammable liquid. The principle adopted is in general the same as that of the explosion pot, the energy liberated in the arc causing the movement of the fluid. Alternatively, in other designs the movement is caused by a piston and is independent of the amount of liberated energy.

Method (2) makes use of the magnetic field of the current to force the arc through the oil in a transverse direction, cooling the vapour and assisting extinction

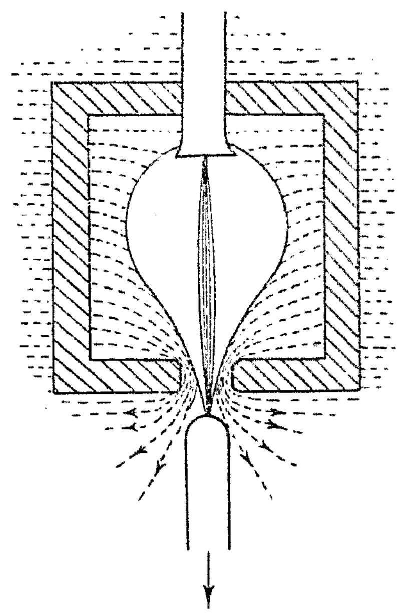

Fig. 1.—Principle of the explosion pot for circuit-breaking.

by turbulence. In one design the field is augmented by insulated iron laminæ against which the arc is forced.

Method (3) makes use of an entirely different principle, resulting from a more direct study of the properties of gaseous conduction. It is well known that for any gas, although the striking voltage at which conduction begins is reduced as pressure or spacing is reduced, there is a minimum which lies around 300 volts. Below this value an arc can only be stuck provided a hot cathode spot is already formed by other means, or, in other words, no arc can be started between cold electrodes with a voltage less (for air) than about 300 volts.

Fig. 2, due to Slepian,* shows the way in which this is applied to circuit breakers. We already know that the rise of voltage between the contacts is extremely rapid after the extinction of the current. A closer analysis shows naturally that the rate of rise is not mathematically infinite but has a large value which depends on the various circuit constants. Put rather crudely, then, successful interruption depends upon the fact that the rate of rise of electric strength of the gas is greater than the rate of recovery of the voltage. By

* See Reference (10).

† See Reference (5).

* See Reference (6).

artificially delaying the latter (which we can do in an experimental plant by altering the circuit constants) we should expect to be able materially to influence the re-ignition. Fig. 2 shows the rate of recovery of electric

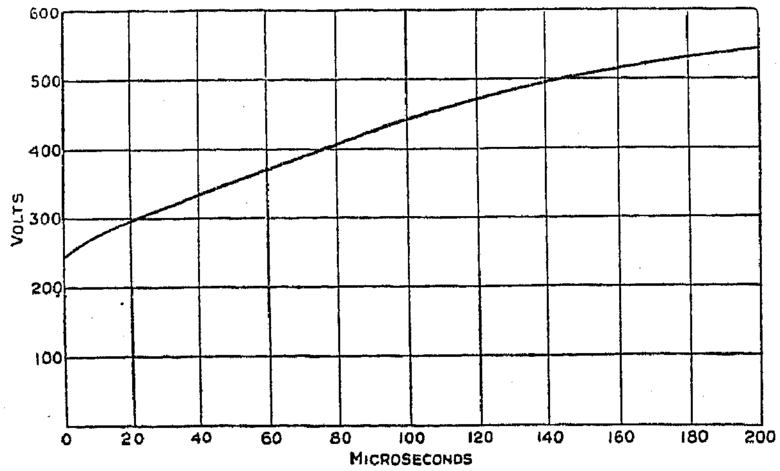

FIG. 2.—Rate of recovery of electric strength of gas after interruption.

strength deduced in this way, and it shows (contrary to expectation) that without scavenging the rate of recovery is quite slow. It does show, however, that the initial electric strength is *immediately greater than* 200 *volts*, so that if the voltage across the arc is limited to this value the current will be interrupted under any conditions. In the circuit breaker using this principle, method 3, the arc is subdivided into such a number of arcs in series that the voltage across each is about 140 volts.

TABLE 3.

Breaking Capacities of Circuit Breakers.

Type	Kilovolts	Amperes	Arc time (secs.)
Explosion pot (oil jet)	140	5 300	0·08
Explosion pot (simple)	140	4 300	0·20
Magnetic in oil ..	110	3 500	0·03
Oil blast (piston) ..	13·2	30 000	0·006
Air blast	12	15 000	0·017
Subdivided arc ..	15	15 000	0·010

Table 3 gives some of the published results which have been claimed for breakers of various types. The figures only form a crude basis for comparison, since such important variables as the asymmetry of the short-circuit current and the rate of rise of re-ignition voltage will differ in the different tests. Moreover, in view of the random variation in the results with any one type of breaker, it is practically more important to compare the *worst* performances rather than the best. Nevertheless the Table is interesting as showing present-day achievements.

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NORTH-WESTERN CENTRE: CHAIRMAN'S ADDRESS

By G. A. Cheetham, Member.

(*Address delivered at* Manchester, *23rd October*, 1934.)

Accurate measurement is essential to the rapid progress of any of the natural sciences. In the early days of development, the pioneers were almost always in difficulty owing to lack of means of accurate measurement; in consequence, they had to turn their attention to the design of suitable instruments. Many of those early instruments are still admired as a combination of excellent theory and mechanical construction.

As the science of electricity progressed, instruments were required not only for investigation but for commercial operation, and the demand for means of accurate and simplified measurement became more and more pressing. There gradually came into existence engineers who were specialists in the design of instruments. It is a psychological fact that achievements of large dimensions present more appeal to young engineers than the design of apparatus of small dimensions; consequently, in the early days of electrical engineering there were many more engineers trained for the design of large engineering apparatus than for the smaller products. Many of the early commercial instruments were therefore designed by men who were instrument makers primarily and who possessed little electrical engineering knowledge. Many of them were guided on theoretical matters by physicists.

As the field of electricity supply and the capital value of electrical plant increased, the need for protection of such plant against damage due to fault disturbances became essential, and protective schemes were devised. A few engineers recognized the value of this development, but within my recollection many engineers considered the cure to be worse than the disease. This was owing to lack of experience on the part of the early designers of protective devices, and also to the fact that the protective schemes generally emanated from engineers unfamiliar with instrument design.

It was not at that time realized that fundamental excellence in both design and manufacture of relays is essential to the success of any protective scheme. The early failures finally produced a group of engineers trained in instrument design, having a thorough knowledge of generation and distribution problems, and capable of making intelligent contact with design and supply engineers for the solution of their protection and measurement problems.

It may be that the phrase "trained in instrument design" causes some surprise, but a little thought will show that the principles of instrument operation cover (without exception) in miniature all the fields of electrical design. As the power expended must be kept small, the available operating forces are also very small; and as most instruments operate mechanically, the fundamental mechanical knowledge of the designer must be sound in order that he may make the best use of the small forces available.

The factors of safety in the mechanical structures must be large enough to ensure reliability, but, because of the small space available, they must of necessity be lower than those on power and distribution plant. As an example of the mechanical stresses forced upon the instrument designer, the stress on the pivot of a supply meter is in the region of 50 to 100 tons per square inch.

The exacting conditions under which accurate measurement is required are clearly shown by the following extract from the specification of one of our Government Departments for the supply of instruments:—

"The instruments shall also remain mechanically and electrically unaltered after subjection to the following conditions: The instrument shall be fixed in a wooden tray hinged at one end, whilst the opposite end rests on a spindle 1-inch square, which shall be made to revolve at 120 revolutions per minute. The duration of the test shall be for one hour."

As this test may be applied under the specification to all grades of instruments, and as the accuracy allowance under the British Standard Specification for sub-standard accuracy on a permanent-magnet moving-coil instrument is 0·2 per cent of maximum scale value, it is obvious that design and workmanship of the highest order are essential to fulfil such exacting requirements.

As the demand for instrument and relay apparatus has increased enormously during the last few years, it has become necessary to make a drastic reduction in the cost of production of such apparatus. This has been accomplished by the design of special tools and machinery, in the evolution of which the trained instrument engineer has played a large part. The instrument designer has therefore to be familiar with the latest workshop methods, and must be trained to design his apparatus to be suitable for manufacture by these methods. As an example of the improvement achieved in design and manufacturing methods of a 10-ampere single-phase supply meter, the selling price is at the present time less than half that in June, 1914. The instrument engineer has also to use every effort along the lines of standardization in order to secure a reduction in cost, and much work has been done in conjunction with the B.S.I. along these lines.

Having shown the necessity for specialist engineers in the design and manufacture of small apparatus, it is interesting to consider the broad lines of progress over the last few years in this branch of engineering.

Instrument and relay design is affected considerably by the discovery of new materials, and the improvements in the strong light alloys of the duralumin type, of synthetic resin, of cobalt steel, and of low-hysteresis ferrous alloys, have had a considerable influence on design. The

copper-oxide rectifier, the photo-electric cell, and the thermionic valve, have also considerably advanced the field of commercial measurement. In the field of special materials, two new alloys, which, it is claimed, give a much greater maximum B/H value than the alloy steels at present in use, have been discovered for permanent magnets. The first is a nickel-iron-aluminium alloy, and the second a nickel-cobalt-titanium-steel alloy. If the manufacture of magnets of those materials becomes a simple practical proposition, instrument design will probably be further affected.

Considering these fundamental discoveries in their order, the effect of the strong, light alloys has been to strengthen considerably the moving parts of instruments, without any increase in their weight. The reduction of weight to a minimum is essential if sensitivity is not to be sacrificed, and strong structures of moving parts are necessary to withstand both the electrical and mechanical stresses set up by the heavy short-circuit currents to which instruments may now be subjected in view of the high kVA capacity of the networks to which they are connected.

The introduction of synthetic resin has also assisted in improvement of the mechanical construction, since it has enabled a designer to combine into one structure a large number of otherwise separate parts. Moreover, it is not only strong mechanically but also a good insulator.

The introduction of cobalt steel has rendered possible a greater stability of permanent magnets. This is extremely important, as in some instruments, such as supply meters, a variation of 1 per cent in the flux produces an error of 2 per cent in registration. When it is considered that a supply meter is guaranteed to operate within $\pm$ 2 per cent for a number of years, the total variation allowable in the flux of a permanent magnet cannot be more than $\pm$ 1 per cent as a maximum. Cobalt steel has also had a considerable influence on the design of apparatus for aircraft, as it has been possible to reduce the weight of instruments, magnetos, etc., without sacrificing the working forces. As cobalt steel can also be successfully cast, magnets of a theoretically correct shape can now be made, to use the steel to the best advantage.

The low-hysteresis alloys have had the greatest influence on the design of instrument transformers, the performance of which has improved very considerably over the last few years. Such alloys can now be used successfully as parts of a magnetic circuit, where previously it was impossible for accurate measurement to use any magnetic material. The efficiency of instruments has in consequence been considerably improved. They have also enabled moving-iron instruments to be made which are suitable for use within commercial limits of accuracy on both a.c. and d.c. circuits.

The copper-oxide rectifier has affected the design of many a.c. instruments. It is well known that the most accurate instruments are of the moving-coil pattern. Whilst with the low-hysteresis alloys moving-iron instruments can be made to register on direct current to a much higher degree of accuracy, an accurate universal instrument can be made from a moving-coil instrument and a rectifier.

There is, however, a possibility of serious errors on a.c. circuits with distorted wave-forms, and in some cases liability to excessive temperature errors, but for sinusoidal circuits and with correctly designed combinations a very satisfactory universal instrument can be made.

Rectifiers have also many other uses than for measurement. They are exceedingly useful in spark-suppression circuits. They can also be used on relay circuits, where, by substituting for a moving-iron relay a moving-coil relay combined with a rectifier, a much higher degree of sensitivity can be obtained. The noise associated with moving-iron relays can also be entirely eliminated.

The photoelectric cell has completely revolutionized the field of photometry and has made the measurement of the actinic properties of light an exact process independent of the human factor. The combination of a photoelectric cell and a miniature moving-coil instrument provides a light, portable apparatus whereby light intensity can be measured directly.

The photoelectric cell also lends itself to the design of ingenious electrical devices for use in production. For example, the counting of objects can be effected by arranging that they cut off a continuous beam of light acting on a photoelectric cell, the variation of the current operating an electrical counter. In America a mail-sorting arrangement has been devised in which the mail-bags for the various localities are each fitted with a disc in various positions accordingly to the locality. The mail-bags at the sorting office are passed along a conveyor, junctions from these conveyors being provided at intervals for the various destinations to which the mail-bags are to be sent. These junctions are operated by the interruption of light on photoelectric cells. In addition to ingenious arrangements of the above type, sensitive automatic regulation of a circuit can be carried out by the light from a galvanometer mirror impinging on two photoelectric cells arranged to raise or lower the current of the circuit.

The large multiplying factors obtained from a thermionic valve have enabled many measurements of very small quantities to be carried out by means of this device, and have in consequence assisted the wireless designer considerably. Thermionic valves are also being advocated for use as relays in protective schemes. They possess advantages in some applications over mechanically-operated relays, but have the disadvantage of a comparatively short filament-life. They have therefore to be duplicated or triplicated, and a comparatively complicated scheme has to be devised for the cutting-in of a new relay in the event of a filament failure.

It is interesting to review the progress that has been made in the various types of electrical instruments and protective gear in the last few years. On moving-coil instruments the original D'Arsonval type of design is still prevalent, the scales have been lengthened somewhat, and a higher torque/weight ratio obtained by the use of cobalt steel. This has been especially useful in the field of pyrometry, where a very small amount of power is available for measurement.

As regards moving-coil instruments, the miniature type has become very popular during the last few years; the momentary overload capacity to deal with heavy short-circuits has been increased by the use of light, strong alloys, and scale lengths have been increased.

Induction instruments have survived because of their

long scale length, their high torque, and their robust nature for commercial measurement. In the existing B.S.S. they are classified generally as "grade 2" instruments because of frequency and temperature errors. They have now been corrected for these errors and can be supplied as "grade 1" instruments. They are very much favoured for switchboard use.

During the last few years the electrostatic type of voltmeter has been revived, and a robust switchboard and portable type of electrostatic voltmeter is available on voltage ranges of 0–150 up to 0–3 500.

The improvement in single-phase a.c. supply meters has been considerable over the last few years. This meter has not changed in fundamental design since its original invention, but the improvements in performance over the last few years have been remarkable. The potential-coil losses have been lowered, whilst the torque/weight ratio has been increased. The accuracy curve of a modern supply meter compared with that of a meter designed 5 or 6 years ago shows very marked improvement. In the older meter an error of 2 per cent at 25 per cent overload was considered normal, whereas many meters at present supplied are within this limit of error at 3–4 times the normal full load. This has been a great advantage to the supply engineer, as it has reduced considerably the changes in capacities of meters for consumers whose loads are gradually increasing.

The amount of investigation over the last few years on pivot and jewel wear has been enormous, and considerable improvements have been effected. The use of oil on jewels has now become almost universal as a factor in the prevention of abrasive rust due to the molecular disintegration of the pivot under the high mechanical stress. The introduction of substances to prevent the creepage of oil from the jewel by reducing its surface tension has also become widely used. Much research has been carried on to reduce the amount of noise emanating from a.c. supply meters, and this has again resulted in increased life of the meter. The insulation of meters has been improved, and temperature correction has been added for important supplies.

On polyphase supply meters the interaction error between the two elements has been practically eliminated and most of these meters now have accuracy curves practically independent of the phase rotation of the circuit. The magnet stability has been improved. The use of the 3-element meter on 4-wire supplies, and of the 4-element meter for summation purposes, has been extended considerably. Where the interaction error is not important, meters have been developed with one disc, thereby reducing the overall size of the polyphase meter.

Considerable advances have been made in the last few years in the design of prepayment meters. The breaking capacity of prepayment-meter switches has been considerably increased, and, in general, this has been attained simultaneously with simplification of mechanical design. This has been necessary, as these meters are now being applied to consumers taking larger domestic loads. Greater accuracy of the coin mechanism, apart from the meter, has been demanded, also a reduction in the mechanical effort required to drive the mechanism. It is possible in a modern prepayment meter to disconnect the prepayment mechanism entirely from the meter without affecting the error on low loads. The necessity for attractive tariffs has brought about special designs of multi-tariff prepayment meters. In connection with prepayment meters which collect revenue on both a time and energy basis, the self-starting synchronous motor has been used, and much ingenuity has been expended on the starting devices. The mechanical devices, whereby the tariff is changed after a lapse of time, or after the collection of a given number of coins, are worthy of study by those interested in the design of ingenious mechanisms.

In d.c. mercury ampere-hour meters, the temperature error of recent designs has been reduced considerably. Meters have been designed which can be completely dismantled, cleaned, refilled with mercury, and reassembled, without affecting the accuracy curve, and the torques of meters have been increased. In d.c. mercury watt-hour meters, recent designs have resulted in the reduction of the hysteresis error, which caused inaccuracy with varying voltages.

The self-starting synchronous motor has also been used for the operation of time switches.

Considerable improvement has been made in oscillography. In the mechanical type of oscillograph, development has resulted in an increase in the number of elements for the simultaneous recording of different phenomena. A 16-element oscillograph has recently been made for short-circuit testing of power apparatus. The complete results of the test are available on one film. The simplification of the interpretation of test results has, in consequence, been considerably increased. The number of papers recently read before the Institution, and the large amount of matter which has appeared in the technical Press on developments in cathode-ray oscillographs, show a great advance in the technique of this subject.

As an example of the ingenuity of the instrument designer, I will mention a method of measuring very heavy currents of short duration. A piece of steel, which has been carefully demagnetized, is placed in close proximity to the line on which the surge current is required. After the current has passed, the magnetism in the steel is measured. As this depends only on the current in the line and on the distance between the line and the steel, it is a simple matter to determine the required current.

The Merz–Price system of protection, in which the current entering and leaving a protected area is measured, and where a difference between these two values isolates this area, fulfils theoretically the most exacting requirements. Where this system can be applied to the protection of plant and transmission lines, and where cost is unimportant, nothing is known that is an improvement on this scheme. It gives perfect discrimination, and as the relays are simple current detectors and do not depend on any time-limit for discrimination they can be set to operate at a high speed, so that the time to isolate the protected area is little more than that required to open the circuit breaker. The only difficulties, apart from commercial considerations, that have arisen in the application of this scheme have been due to the electrical capacitances of the pilot wires and the lines. A few schemes have been devised which overcome this difficulty,

such as compensated pilots, the Translay system, etc. These, however, do not detract from the statement that the original scheme is almost theoretically perfect, and I am emphasizing this point because it is many years since the scheme was devised by British engineers.

On long transmission lines and cables the cost of installing the pilot wires necessary for the operation of this scheme becomes serious, and modern development on protective gear has been to devise satisfactory schemes which do not require pilot wires. Since the advent of the improved induction-type relay, a time-delay has been obtained to a high degree of accuracy, and perfect discrimination can be obtained with a time difference between two relays of from 0·2 to 0·25 sec. The disadvantage of this scheme is that the relay nearest to the generating source must have a comparatively long time-delay, and if the fault is near to the generating station a considerable disturbance may take place before the fault is cleared. It is evident that the utility of this scheme can be extended as circuit-breaker speeds are increased, as the determining factor for the difference of setting between two adjacent relays in the protected chain is determined by the length of time the circuit breaker takes to open.

The first development to reduce the time of a disturbance near the generating station was that of the impedance type of protection. An impedance relay has a time-lag which is proportional to the voltage across the fault loop and inversely proportional to the current flowing in the fault, that is, is proportional to the impedance of the fault loop. Assume that we have a line that we wish to protect having an impedance of 50 ohms and that we wish to divide this into five protected sections, each of 10 ohms impedance, and that a relay is situated at each of these five points. If we arrange the relay at the generating station to have a time-lag of 0·25 sec. when the line is short-circuited at this point, and a time lag of 0·75 sec. when the line is short-circuited at the next point further from the generating station, and if the impedance time-lag curve of this relay is a straight line, it will operate with a proportionally longer time-lag, up to a maximum of 2·75 secs., with a short-circuit at the point furthest from the generating station. If the relay at the second point from the generating station is similarly set to operate at 0·25 sec. with a short-circuit at this point, and the remaining relays are similarly set, it will be seen that the time for a disturbance on the whole of the line can only reach a maximum of 0·75 sec., and this scheme can be extended indefinitely.

Some objections were raised to this scheme on the grounds that if an arcing fault occurred, the resistance of the arc would be appreciable compared with that of the lines and would upset the theoretically correct operation of the system. The advocates of this latter theory modified the impedance scheme, by arranging that the voltage applied to the relay was the idle component of the voltage instead of the total voltage. The time-lag of the relay according to this arrangement was then proportional to the reactance of the line, instead of to the impedance, and an arcing earth did not then affect the theoretical operation. The supporters of the impedance scheme claimed that reactance measurement added to the complexity of the scheme, and that the arc trouble was exaggerated, as the resistance of the arc is negligible at inception when measurement is made by the relays. This controversy has been waging for some time, but now that the Central Electricity Board have portions of their system protected by both types of gear, impartial evidence should shortly be forthcoming which will add to our knowledge of the two schemes.

It is evident that both the impedance and reactance methods of protection have departed entirely from the Merz–Price principle. One method on which development has been taking place for some time which is closely related to the Merz–Price principle is to carry the pilot-wire current along the lines themselves by means of carrier currents. These currents are injected into and taken out of the line through capacitance paths, and on straightforward single-line protection the scheme is quite successful. The principal weaknesses in such schemes are that thermionic valves have to be employed in the generation, distribution, and amplification, of the carrier currents, and the difficulty of preventing radiation from one circuit to another. When one considers a complicated network in which the pilot-wire currents have to be restricted to certain paths, some method of discriminating between the various pilot currents must be used, such as varying wavelength rejector circuits, etc. This is a very difficult matter, but already much time and thought have been expended on it.

Referring now to relays, there has been a great deal of development for some years on the breaking of a circuit in a vacuum. Medium- and small-sized circuit breakers have already been built. Within the last few years relays have been designed in which the whole mechanism is *in vacuo* and the mechanism operated by electromagnetic means through the envelope, or by the expansion of a hot wire. These relays are capable of dealing quite successfully with currents up to about 30 amperes at 1 000 volts. They occupy a very small space and are less expensive than electromagnetic relays. Being hermetically sealed, they are free from troubles due to dust and atmospheric conditions. They are capable of working under chemical fumes and, apart from the contacts, there is no deterioration of the parts of the relay. The hot-wire types are also perfectly silent in operation. One type of relay has a bimetallic strip, with or without heating coil, also enclosed in the tube and operating directly on the contacts. These can be used for thermostatic control of liquids, etc., by immersing the complete relay. In the hot-wire type of relay, various time-lags can be obtained dependent on the proportioning of the hot wire, etc. These relays should find quite a large application in the future.

The use of a synchronous motor geared to clockwork as a timepiece is becoming more popular, and it is obvious that when the public fully realize the accuracy, convenience, and freedom from trouble, of this particular form of clock the demand will be very considerable. Architects and builders are already making provision for wiring behind mantelpieces, and some makers are already incorporating the clock into household fittings. These are steps in the right direction, as the housewife will demand concealment of wires to clocks before she will give them her final blessing.

The supply authorities have assumed the responsibility

for controlling the frequency of their supply sufficiently accurately for time-keeping purposes. This is now almost universal throughout the country. It is evident, however, that, when stations are interconnected, if attempts are made to control the frequency from the various interconnected stations individually, without any prearranged plan, violent fluctations of load will flow along the interconnectors. It is also clear that, with the interconnection of a few stations and where the capacity of one station is large compared with that of the remainder, the frequency control can be left to the large station, the remaining stations operating to a load schedule. The greater the number of stations interconnected, the greater will be the difficulty, however, and it may be necessary to take over automatically the control of frequency and load.

A scheme has already been devised to carry out this function, which briefly operates as follows. In each of the interconnected generating stations is fitted a master clock, which need not be capable of astronomical accuracy but should keep reasonably good time. Connected to the busbars is a synchronous motor driving a contact device, which is arranged to compare the time-keeping of a synchronous motor with the master clock every few seconds. If during the period of comparison the frequency is increased in advance of the master clock, the servo-motors on the turbo-generators are operated so as to reduce the steam supply by a small amount periodically repeated. The amount the governor is altered each period is proportional to the deviation of the electrical time from standard time. To each generator is connected a load relay, which is capable of being set to any percentage of full load at which it is desired it should operate to schedule. Considering the case mentioned above, in which the electrical time has gained on the standard time, the reduction of the steam supply reduces the load on each generator. When on any individual generator the load has been reduced below the schedule setting to an agreed tolerance, the lowering impulses to the governor servo-motor are cut off. The final result in the station is that the total steam supply is reduced until, in the limit, the load on each generator falls below the schedule by a given tolerance. After this has happened, the frequency-control device ceases to function. It is evident, however, that if this device is fitted in all the important stations, and if this action occurs simultaneously, the result will be to correct the frequency. It is considered that with this device the accuracy of the supply frequency can be maintained to a very high value. With reference to the statement made previously, that the clocks did not need to operate to a very high degree of accuracy, a provision is made on the device to show the difference between standard time and electrical time. If the load controller periodically gives the correct difference which should appear on this scale between the standard clock and the electrical time, the control room in each station can very simply alter this scale on the device without touching the standard clock. Astronomical accuracy of the clocks is therefore unnecessary.

The fully-automatic control of hydro-electric generating stations and convertor substations has been an accomplished fact for so long that novelty only occurs in detail. The distance control of stations over pilot wires is a tribute to the close co-operation of the supply engineer, the telephone engineer, and the instrument engineer.

The electrical engineer in his quest for higher efficiencies is leaving no field of generation unexplored, and greater attention is being focused on the boiler house. It has already been proved that the automatic operation of boiler plants results in considerable economy in fuel. There are many systems of automatic control of boiler plant, all of which incorporate relays and ingenious electrical devices. The instrument engineer is becoming more and more established in the boiler house, and it is confidently expected that more development in the control of the boiler will take place in the near future, resulting in higher thermal efficiencies.

Because of its association with control problems, the instrument engineering industry must, of necessity, be faced with the solution and development of many special engineering problems. At the same time it is necessary for it to develop its manufacturing resources to the highest degree of efficiency, in view of the large amount of competition from all parts of the world. It has occurred to me that, whilst the electrical engineer individually is seeking for a maximum of result with the minimum of expenditure in the design of his apparatus, the industry as a whole falls very far short of this ideal. In my opinion a much closer co-operation inside the industry would result in the agreed division of special development between its members.

Special development is necessary, is always costly, and is generally unprofitable, as the volume of this business is usually too small for all the participants to be able to include their development in the highly competitive selling price. The division of this special development amongst the industry without duplication would enormously reduce the expenditure by the industry on development, and would leave it free to devote the whole of its engineering resources to the improvement and more efficient production of its standard products. Whilst special engineering achievements are important, especially if spectacular, the vital factor affecting our position in the world of engineering is the quality and price of our standard products, and any steps which will release more engineering activity towards the perfection of our standard engineering products will increase the prestige of British industry in the world of engineering.

SCOTTISH CENTRE: CHAIRMAN'S ADDRESS

By Professor F. G. Baily, M.A., Member.

"BEFORE 1900 AND AFTER."

(*Address delivered at* Glasgow, *23rd October*, 1934.)

My association of 45 years with the Institution gives opportunity for a survey of the development of invention during the period. An examination of the period and some 12 years before showed that a distinct line could be drawn at the close of the last century, or at most a few years after. In the years before that date almost all of the ideas which now form the basis of electrical engineering practice had been put forward and to some extent developed. The stretch of time that follows has been occupied in further development, increase of magnitude, improvement in design, efficiency, and cost of production. These have called forth a great number of subsidiary inventions, and in some cases the present forms are very different from the early patterns. But the period after 1900, with one or two conspicuous exceptions, has been poor in real and important novelties, although a time of wonderful general advance. A statement of this sweeping character requires justification, and the various parts of the practice of electrical engineering will be discussed from this aspect.

Beginning with d.c. generators as the leading item in the old days, these were in 1880 still in the experimental stage, but by 1890 the 2-pole generator was a reliable and efficient machine, built to strict specification as to speed, voltage, and temperature-rise. The historic Royal Society paper by J. and E. Hopkinson on "Dynamo Electric Machines" in 1886 had put the chief calculations on a sound basis, and Ewing's "Magnetic Induction in Iron and Other Metals" in 1891, as well as earlier papers of his, explained much that had been obscure. The multi-polar form of field magnet and the carbon brush were coming under trial in the early 'nineties, and the series-excited commutating pole was invented by Mather and the compensating field winding by Ryan about the same time, but since the 2-pole field magnet did not lend itself to these improvements, some years passed before they came into use. Natural ventilation of the armature was well understood, fan ventilation was being tried, and automatic lubrication was provided.

Alternators from the earliest times have passed through a wonderful variety of designs, for while a bad design in a d.c. machine is shown up at once by sparking, a mistakenly shaped alternator merely produces an irregular wave-form, which is not so obvious. The present universal design was actually one of the early forms, but it had no success and died out. Armature reaction and wave-form were disregarded in those days, but it should be noted that some of the first effective patterns, such as the Ferranti and Siemens disc alternators, the Westinghouse drum pattern, and one or two others, gave good wave-forms. An old machine of about 1891 in the laboratory at the Heriot-Watt College was very useful to me as a source of a reliable sine wave. The endeavour to reduce the large exciting-current loss and the attractions of a stationary armature produced designs in which wave-form distortion became almost ludicrous. The single exciting coil was the favourite idea for some years, and inductor machines and compound-wound alternators were other examples of blighted hopes. They were all wiped out by the devastating pictures produced by Duddell's oscillograph, and the records of this instrument have been as potent as the indicator diagram was with the reciprocating engine, and as the cathode-ray oscillograph is proving in switch and fuse design.

While not an electrical invention, one cannot pass from generators without reference to Parsons's steam turbine, for its marvellous development has controlled the alternator, and its excellence and unsuitability for d.c. generators have done much to eliminate the latter. The Parsons turbine was exhibited at the Institution of Civil Engineers about 1890, a 20-h.p. machine running at 30 000 r.p.m., and before ten years were past the steam turbine was pushing its way into electric supply stations, from which it has ousted all others.

Passing from the generators to the distributing system, Ferranti's Deptford to Bond Street 10 000-volt single-phase transmission by buried cable, opened in 1890, claims pride of place, and it retained this honour for many years. While his method of manufacture has long been superseded, and was in fact never imitated, his insulator—waxed paper—is supreme. Its only and quite recent competitor, fluid oil with a cellulose fibre filler, was actually invented by Brooks about the same time. He used thick resin oil and had reservoirs to keep a pressure on the oil, with means of holding back the oil when outlet boxes were opened. High-pressure transmission was given a further demonstration in 1891, when 100 h.p. was transmitted from Lauffen to Frankfort, 110 miles, by 3-phase overhead line at 30 000 volts. Here again nothing surpassed this achievement for many years. High-tension transmission was not in favour, and d.c. distribution by Hopkinson's 3-wire system was general. The enthusiasm and courage of Ferranti could make no impression on the sound policy of Col. Crompton and A. B. W. Kennedy, to both of whom alternating-current was suspect. Fleming's "Alternate Current Transformer" in 1889, and Heaviside's "Electromagnetic Theory" in 1893, showed the theory, the latter giving far more than was needed at the time; but the d.c. dynamo was a reliable

machine, and there were no such surprises in the distribution as the alternating current was apt to show.

The network of low-tension cables has changed little since early days. Some of the varieties, such as the bare strip in culvert, disappeared many years ago, but the draw-in system with brick chambers for taped joints, and armoured cables with lead or iron compound-filled joint boxes, have continued almost unchanged. It can scarcely be claimed that perfection has been reached, and it is generally admitted that distribution is less satisfactory than generation, so the apparent contentment with the old ways is the less intelligible.

The transformer stands half-way between generators and the distributing system. It was one of the earliest of electrical devices, and in principle little scope for novelty is possible. Beyond the use of oil immersion no substantial alteration has been successfully introduced for many years, and while commercial voltages have greatly increased it may be recalled that Siemens Brothers showed a 20-kW 50 000-volt transformer at the Crystal Palace Exhibition in 1891, and James Swinburne & Co. had one for 80 000 volts on their stall. These were built with nothing but cotton and shellac insulation, though there may have been sheets of press-spahn between layers. The 50 000 volts and output were genuine enough, for the Siemens transformer lit up a great bank of 500 lamps in series, each taking about 34 watts at 100 volts. Like the Lauffen transmission earlier in the year, these demonstrations remained as *tours de force* for a long time. Indeed, nearly 20 years later I found that manufacturers had some difficulty in providing even a similar transformer.

Insulating materials of the last century were ebonite, mica, porcelain, stoneware, vulcanized rubber, and waxed or varnished paper and cloth. The paper and cloth materials have much improved of late years, but the others are still pre-eminent in their own lines. There was little of moulded compounds in those days, though a mica- and shellac-moulded insulator for the trolley wires of tramways gave good service. In this century a great variety of moulded composite materials were brought forward, with poor results until bakelite was invented. Bakelite has been a notable advance, for while it is no great insulator its remarkable merits for moulding, its endurance of fairly high temperature, mechanical strength, and small absorption of water, raise it far above the other composites, and enable it to replace porcelain in electric fittings and shellac in varnished paper and cloth.

Mineral and resin oils have been known and used for a long time, but the fairly recent realization that they normally contain traces of water, which is most prejudicial to their electric strength, and the discovery that this water can be removed mechanically, has been of first importance.

The applications of electricity to every branch of industry and every aspect of modern life have certainly increased enormously in this century; but to a considerable extent the increase has been brought about by an application of early apparatus and methods to a larger number of things and processes.

Motors range now from the tiny machine in the electric clock to the 10 000-h.p. motor of the rolling mill. The former recalls Lord Kelvin's "mouse mill," devised for the early submarine work, and the large one contains little that was not known in 1900. The Ward Leonard combination that is used in this connection was invented in 1891. What has been said above concerning d.c. dynamos refers also to motors. In alternating-current work the series commutator motor was invented by Wilson in 1888, though its use in electric traction did not begin until 1903. Since then it has been improved by the compensating winding, but the curious Winter–Eichberg variety has not held its place. The repulsion motor, also of this century, is both ingenious and useful.

The plain induction motor dates back to Ferraris's work in 1885, while the principle of the rotating field produced by 2-phase currents, and the resulting rotation of an armature by eddy currents, was shown by W. Baily in 1879. Tesla followed in 1888 with a complete scheme of 2-phase alternator and induction motors, and since then the only marked improvements have been the double winding on the squirrel cage and the production of variable speed by the injection of extra voltage into the rotor. While the increase in starting torque and the control of speed are respectively of great use for some purposes, most of the polyphase induction motors of to-day are substantially the same as those sold in 1900. The cascade combination was known, though only beginning to be applied, and even the variable speed by e.m.f. injection was proposed in the early years of the century, but the additional complication of the commutator was regarded as a serious objection. Synchronous motors as reversed alternators were of course known as soon as the running of alternators in parallel was realized, and the *Journal* of the early 'nineties is full of discourses on this. The self-synchronizing motor with short-circuited compensating field winding came early in the century, but the auto-synchronous motor is fairly recent.

Rotary convertors came out before 1900, and the motor convertor of Bragstad and La Cour was invented in 1902. Phase-advancers, though ingenious, have not found any extensive use and need not be considered.

While the use of electric motors has vastly increased in the last 30 years, the development is due rather to the more widespread supply of electric energy, and the reduced price of both motors and energy, than to any great improvement in the suitability of the motor for the work. There were many different applications before 1900, but each one showed only few instances of use.

The heating possibilities of the electric current were recognized very early. Omitting lamps for the moment, electric fires and cooking utensils were available in the 'nineties. Crompton advertised an electric kitchen in 1892, with a picture quite in the modern style. Elihu Thomson's butt welder was shown in 1890, and arc welding with the carbon arc, used either as a blow pipe or with the work as one electrode, soon gave rise to various patents. The spraying action of the iron-wire electrode is, however, a more recent discovery, and one of outstanding importance.

Furnaces were a very early idea. Sir William Siemens began in 1878, and devised both the free-arc pattern, afterwards developed by Moissan and Stassano in the 'nineties, and the arc resistance type, the forerunner of

the majority of the furnaces of to-day, and used by Hall and Heroult for aluminium and Willson for calcium carbide, all before 1900. The Cowles brothers were at work in 1885 with their resistance furnace, followed by Acheson's carborundum furnace in 1891. A few years later came the various forms for producing nitrate from the air, though the commercial scale was not successful until after 1900. The report of a Commission appointed in Canada in 1903 to examine the electrothermic processes in use for iron and steel is a large volume, and shows that a great variety of furnaces of large size were in considerable use at that time. The induction furnace was patented by Ferranti in this country and by Colby in America in 1887, Ferranti being the first by three months, but it was 10 years before the invention was brought to a commercial scale by Kjellin.

Much work was done in the 'nineties on electrochemical processes. Electro-deposition of metals was an old story by that time, the Castner–Kellner sodium furnace and the aluminium furnaces mentioned above were being developed, and many valiant attempts at making chlorine were made, some attaining to a short-lived commercial trial. Whether as a red-hot gas in the fusion cell, or in solution in the wet cell, chlorine was a difficult proposition.

Electric railways and tramways were early examples of the use of electricity. In 1887 Sprague was developing overhead trolley-wire trams, rapidly arriving at single reduction gearing, spring suspension, and the drum controller. Series-parallel control came in the 'nineties, so that by 1900 tramways were practically in the form used to-day, except for the addition of the slipper magnetic brake. Various other patterns, such as slot and surface stud systems, were tried for a long time but have now disappeared in most places. It is interesting to note that Prof. Kapp, in his book "Electric Transmission of Energy" (1894 edition), writes "For town traffic the trolley is inadmissible, or at least has not yet been sanctioned by the authorities." It was some years before the sanction was obtained in this country.

Passing to railways, the City and South London tube railway was running in 1890, using locomotives, and the Central London followed soon after, using motors on the coaches. Both were third-rail, 500-volt d.c. systems, and others on the Continent followed rapidly. Alternating-current systems were at first 3-phase with induction motors, and the single-phase series motor was not brought in until 1903 in America.

The remarkable experiment of the Berlin–Zossen railway in 1901 must be recorded. A speed of 100 m.p.h. was attained, but the permanent way did not act up to its name for long at this speed. It was a 3-phase system with overhead wires at the side of the track.

In house wiring, as with cable systems in towns, little change has been made since about 1900. At that time vulcanized-rubber-insulated wires and screwed steel piping were recognized as the best job, with distribution boards much as to-day, though the boards have been improved in design. Tumbler switches, 2-pin plugs, and other details were in use, though some other patterns went on for some years. Round about 1900 was in fact the beginning of the present system of wiring as a definite draw-in scheme with earthed mechanical protection. The lead-covered twin system came later as a scheme, though lead-covered wires had been freely used in house installations. The earthing of apparatus, lightheartedly ignored in those days of 110 volts, seems still a questionable matter, if one may judge from the frequent absence of any facilities for earthing, and their makeshift character when they are provided, suggesting that if the earth connection does break it will not much matter.

Lamps have shown a curious development. The arc lamp of Davy was for a very long period pre-eminent for outside work, especially the d.c. arc, which gave without further trouble an excellent distribution over the ground. The mechanical parts gradually advanced and the arc sputtered and hissed less, as carbons and regulation improved. The enclosed arc was not an improvement, except in saving of trouble in re-carboning, but the flame arc, brought out about 1904, was brilliant, if more troublesome to look after. When war broke out it was realized that nearly all the arc carbons in the world were made by Conradty in Austria. The supply came to an end, and arc lamps were useless. They have never recovered their old position, though they continue in places, but whether they will survive against the competition of the new luminous gas lamp is doubtful.

Filament lamps began commercially with Swan and Edison in 1880. The carbon filament continued unchallenged and almost unaltered for over 20 years. Then in 1904 von Welsbach made the osmium lamp, which proved too fragile. The tantalum lamp soon followed, then the sintered tungsten filament, also fragile but so highly efficient that breakages were condoned. Finally the hammered tungsten wire was achieved and all other lamps disappeared. The spiral in the gas-filled bulb was the last improvement. The Nernst lamp had a short run of popularity just before the osmium lamp was brought out, and Cooper Hewitt showed his mercury-vapour lamp in 1901, the practical development of the old Geissler tube, and the forerunner of the luminous gas lamps of to-day. In 1900 4 watts per candle was the consumption for the filament lamp, and these new lamps give about 6 candles per watt. In glow lamps this century can claim a remarkable series of inventions.

Accumulators may be dealt with in a few words. They were a working proposition in 1881, and by 1900 the development of the lead-plate cell was almost complete. Its character has been little changed for nearly 40 years, and the property of chief importance, durability, has not much improved in my experience. A life of 10 years was obtained in batteries laid down before or about 1900, and that would be considered quite good to-day. Edison's alkaline cell was devised and talked of about 1895, but some years passed before it was marketed. Other inventors have introduced modifications, and its ability to withstand even violent vibration gives it a place for special purposes.

Telegraphy was perhaps the first application of electricity, Schweigger, Cooke and Wheatstone, and Henry, being improvers on Ronalds's electrostatic system. Duplex, quadruplex, which was one of Edison's early

inventions, multiplex, Hughes's type printer, the high-speed Wheatstone automatic, were all some time before 1900, and for years after that the progress was slow. In the last 10 years or so there has been a notable advance in labour-saving devices and economy of line wires. Transmission of pictures has made a new feature for the Press, and the wires carry a simultaneous multiplicity of messages undreamt of in early days.

The main principles of telephony were well established before 1900, common-battery working and multiple boards being well known, and for a long time this sufficed. There were strenuous attempts to devise a satisfactory telephone relay, but the problem was too refined for mechanical movement and the solution had to wait for the amplifying valve. The automatic exchange forms the chief novelty in the public eye, and this was actually invented shortly after 1900, but only applied to a few telephones between rooms in an office or departments in a factory, so that its whole development belongs to this century.

Much of the advance in speed of signalling and distance covered has been due to the Pupin coil, and this was advocated by him in 1900, while the invention was a direct application of the theory laid down by Heaviside in 1888, and definitely recommended for the improvement of telephone transmission. The inventors of even those busy 10 years were sometimes slow in grasping an opportunity.

Wireless telegraphy is regarded as a product of this century, but Lodge in 1894 demonstrated some of its possibilities, and in 1896 Marconi began his great work. Various coherers were rapidly invented, transmitters were made more powerful, masts increased in size, and distances grew immensely. But Fleming's rectifying valve was the beginning of modern wireless. The principle of a one-way circuit was by no means new, and the electron stream from a hot body was known, but the practicable and efficient valve was not achieved until 1904. Two years later Lee De Forest added the third electrode, and the amplifying valve was born —a simple device, but probably the most noteworthy electrical invention of this century. The subsequent developments in many directions are too recent and well known to require description.

Measuring instruments and methods have shown a steady improvement rather than conspicuous novelty. Improvements in magnet steel and permeable iron, and fineness of suspension wires, have played their parts. The quartz fibre, one of the essential elements in delicate work, was invented by Vernon Boys about 1890, and was rapidly appreciated. The oscillograph of Duddell came out in 1896, and Braun's cathode-ray tube was devised as a measuring instrument in 1897, being based on J. J. Thomson's tube by which he measured e/m. Braun's tube, now called the cathode-ray oscillograph and considerably elaborated, was rapidly recognized for high-frequency work, though it did not produce the dramatic results of Duddell's pattern. Vibration and thermal galvanometers came in this century. Previously one had to use a soft-iron galvanometer with a formidable self-inductance, when very small alternating currents were to be measured. The a.c. potentiometer is also modern, possibly because in early days no one wanted to make the measurements it performs. The chief change in experimental power has been due to the amplifying valve. By its aid the limits of measurement have receded a long way, and the super-sensitive galvanometer, a very patience-trying instrument, is not so much required. The valve has also opened up such new methods as photometry by the photo-electric cell, in place of the old bolometer.

Commercial instruments have altered little, but they are more accurate. A considerable improvement has been achieved in wattmeters, due to a better understanding of their errors, which in the old patterns were numerous and misleading.

Röntgen's discovery of his well-known rays and their selective penetrating power in 1895 was epoch-making. It immediately received wide recognition, and inventors were soon busy at developing the tube. While modern tubes, such as the Coolidge, are very much more powerful, the design is substantially the same, and the increase in power has been made possible by the high-tension apparatus developed in this century, and the rectifying valve. The mechanical rectifier, sometimes used, recalls Ferranti's old rectifier for d.c. arc lamps in series.

Apparatus for producing millions of volts has in the last few years been a conspicuous feature, and some of the devices are very bold. The electrostatic ones remind us perhaps of Wimshurst's machine, but the lay-out is much changed and the power vastly increased. In a.c. working it is well to recall the great results of Tesla's transformer and an old picture of the inventor in his laboratory, surrounded by lightning flashes yards in length. The actual picture may possibly owe something to the ingenuity of the photographer, but the enormous voltages were really produced.

The rectification of alternating currents begins with the discovery, in 1856, of the action of aluminium in an electrolyte, and the use of this property to rectify alternating currents in 1876, leading to the Nodon valve in 1904. At this last date the Research Department of the General Electric Co. of America had discovered the rectifying action of the mercury-vapour lamp and were developing apparatus to deal with substantial currents or give several thousand volts (d.c.), so that in 1905 the Company was supplying sets for running d.c. arcs in series and for charging batteries. Mr. Cooper Hewitt made the same discovery and brought out his rectifier in 1902. The whole subject substantially belongs to this century, and may bring about changes of practice in several directions, for the use of a third or grid electrode opens out great possibilities. Mechanical rectifiers, such as Ferranti's, were in use in the 'nineties.

The statement that the year 1900 marked approximately the end of an epoch of electrical invention of notable character has been borne out by the foregoing analysis, which if not exhaustive has shown the main features. The early inventors exploited all the possibilities of the normal electric current in all its properties —thermal, magnetic, and chemical—with exhaustive thoroughness. Their foresight had often too long a range for their pecuniary advantage, for many master patents ran out long before the object came into general use. In some cases subsequent discovery or invention

in another line greatly helped to success. To take a humble instance, the electric cooking utensil had little chance in 1892 when the unit cost at least 6d., but the reduction of the unit to ½d. makes all the difference to the cooker. This striking reduction in the cost of electric energy exemplifies much of the work since 1900. The discoveries and inventions were practically all there at the beginning, and the years have been spent in gradual improvement and subsidiary invention, effecting reductions in loss after loss, though no single improvement can claim more than a small share. Size itself has been a chief cause, not only directly, but indirectly by making advantageous many small savings, which in a small plant would not be worth their cost. In this direction most of the advance has been brought about by the mechanical engineer, for even in 1900 there was little to be saved off the efficiency of the alternator and transformer. It may be claimed for electrical engineering that it has opened up for the mechanical engineer a large field, which he has not been slow to cultivate.

If a schedule of dates be made, it will be found that the quarter of a century from 1875 to 1900 was a time of activity, with a short but important outburst between 1903 and 1906. Then followed nearly 20 years of quiet development, part of the time being occupied by the War, which compelled attention to other issues. The last 10 years have seen at least great developments, almost constituting novelties.

That a period of consolidation was required need not be taken as a reflection on the originating ability of the period. Manufacturers, who had been compelled to prove all things, were glad to hold on to that which was good. The lamp makers, however, who had had a long period of monotonous repetition, welcomed a spirit of novelty. Even in a new subject like wireless, the amplifying valve of 1906 was slow to develop. In 1914 there were few samples available for experimental use and little was known about them, though progress was rapid in the years which followed.

Another possible cause may be suggested. In the early stage, when everything is on a small scale, even the amateur can try out an idea, and an educational laboratory may experiment with apparatus and machinery representative of current practice. But that stage passed and for many years nothing took its place. The last 10 years have seen the growth of large-scale experimental work in the factory research laboratory, where expenditure far exceeding the powers of private people or departments of engineering has been freely incurred. It may be partly through this new influence that the recent change has come, and its continuance may therefore be expected.

IRISH CENTRE: CHAIRMAN'S ADDRESS

By R. G. ALLEN, Member.

(ABSTRACT *of Address delivered at* DUBLIN, *25th October*, 1934.)

The subject of this Address is "A General Study of the Main Features in the Development of the Electric Motor."

In a study of the development of important machinery there may be much which it is profitable to consider, apart from its constructional and operational advancement and the growing use of particular types. For instance, there are the secondary developments which arise from the main development, and the operations and interactions of the psychological, technical, and commercial factors which, usually in a complex manner, determine the nature, scope, and rapidity of the development. Here too, as in other cases, the commercial factor, as represented by the complicated mechanism of demand and supply, exerts a predominating influence.

In the earliest stages of its development the electric motor must have appeared as a monstrosity to the mind of the mechanical engineer—a veritable cuckoo in the nest of engineering. Never before had one met with such a mixture of wire, iron, and the play of intangible forces. There were copper bars separated by mica and held together by insulation and plates; and, riding upon this, chattered copper brushes held precariously in holders attached to a rocker ring; while on top of all this the inevitable sparking might well have burnt up hopes for the future of the machine. Yet, wonderful to relate, it did what it was required to do, and with resolute handling became the means of sharpening the wits of the engineer and of giving him much to overcome.

The chronological steps in this development are given in Table 1, and it may be said as a supplementary statement, that the general trend of development was not unduly affected by commercial necessities or impositions, until the machine had developed in construction and operational efficiency to nearly a stationary point. Then the factor of intense competition soon reacted upon the manufacture of the very materials themselves and resulted in the production of materials with improved magnetic, electric, and mechanical properties, which have enabled the engineer to run electric machines at higher speeds and with heavier magnetic and electric loadings. As a consequence, the weight per horsepower has been much reduced.

The development of commutation began with the use of copper brushes and brush lead, but this stage was marked by low commutable currents and severe wear and tear of the commutator. Then followed the use of carbon and graphite brushes, which gave higher commutable currents and less wear and tear of the commutator. Interpoles were patented in 1890, but it was not until 1900, i.e. 10 years later, that they began to be widely used.

The function of interpoles with regard to commutation is practically ideal, and as their windings carry the load current (or a fixed proportion of it) no troublesome rocker-ring displacement is required. Thus the value of the current which could be commuted sparklessly was raised by their use well beyond that which could be commuted without them, so that, in general, the thermal limit

TABLE 1.

An Approximate Chronology of the Main Events in the Development of the Electric Motor.

1831	Birth of the electric motor (Faraday).
1835	Small commercial generators began to be constructed.
1865	Self-exciting machines were first used.
1872	Ring armatures were being replaced by the drum type.
1877	Birth of the synchronous motor.
1879	Birth of the induction motor.
1889	Carbon commutator brushes were suggested.
	Patents taken out for commutation poles.
1890	Construction of commercial rotary convertors began.
	Squirrel-cage induction motors were first built.
	Birth of single-phase commutator motor.
1892	Commercial use of carbon brushes began.
1898	Double-winding rotor for squirrel-cage type of induction motor was invented.
1900	Commercial use of commutating poles began.
1902	La Cour cascade convertor was patented.
1905	Single-phase commutator motors were suggested for railway electrification.
1906	Interpoles began to be used for rotary convertors.
1908	Adoption of single-phase commutator motors for certain railway lines.
1914	Schräge variable-speed induction motor began to be commercially used.
1915	Alexanderson's split-phase convertor was adopted for work on the Norfolk and Western Railway, America.
1916	Subdivided deep rotor bars were used for squirrel-cage motors.
1921	High-reluctance interpoles began to be used for railway rotary convertors.
1924	Double squirrel-cage windings were being used commercially.
1932	Kando railway convertor system was tested and put into commission.
1933	Thyratron commutator motor was tested.

alone became the limiting factor in the design of interpole machines.

Besides improved commutation the use of interpoles brought in its train a number of advantages, notably a much higher output capacity for wave-wound motors and a more extensive range of speed variation for shunt motors.

In view, therefore, of the value of interpoles, the cause of the hiatus, or 10 years' pause, between their patenting and commercial use, is worth considering, if only for its psychological features. Indeed, this matter has received attention from H. M. Hobart in a recent paper* in which the facts of the case, and the reason of this lapse, have been well presented.

Briefly stated, it may be said that a very elementary conception of armature reaction, a simple acquaintance with commutation, and a concentration on the location of the interpole in the magnetic system, would have informed one that before the interpole could be other than a menace to good commutation it must, in addition to being of right polarity, have in the first place enough ampere-turns on it to neutralize armature reaction, and then additional ampere-turns for the purpose of commutation. These ideas were, however, strangely confused in the minds of engineers at the time of the introduction of interpoles, and the adoption of the latter when wrongly designed often proved a hindrance rather than a help to good commutation. It is remarkable that it took 10 years for the minds of expert engineers to become clarified on the matter. It was a technical aberration and not a commercial obstruction. As such, it suggests among other things the necessity of intimate technical knowledge of machinery and apparatus, and so justifies the existence of universities and technical colleges in tune with the needs of the industrial world—but not wholly in tune. The industrial and commercial world wants results, and wants them quickly. It has but little use for humour—the humour of a scientific man spending years at heavy research work in obtaining a valuable negative result.

After the general use of interpoles had more than justified their adoption, a further problem involving commutation, namely that of designing rotary convertors for use on 50- or 60-cycle supply systems, was thrust upon the consideration of the engineer. For ordinary operations this was undoubtedly a difficult matter, but much more so when these machines had to supply traction motors.

Now the development of the rotary convertor was somewhat fortuitous in nature. For, in the early days of electrical engineering, plant had been installed in the United States of America for supplying power at low frequency, so that there in particular the development of the rotary convertor became at this low frequency an operational and, later, a commercial possibility. America and Germany both introduced this type of machine in 1890, and commutating poles were added in 1906. With such a good start, rapid headway was made, notably in America, in rotary-convertor design, so that the superstition that above a frequency of about 25 cycles per sec. the rotary convertor is unreliable was soon exploded. In 1900, sixty 1 500-kW rotary convertors at 60 cycles per sec. were in operation on the Manhattan Railway and the New York Subway.

* H. M. Hobart: *General Electric Review*, 1928, vol. 31, p. 519.

In 1921, high-reluctance interpoles on 60-cycle railway convertors were introduced, the high reluctance being produced by brass distance-pieces between the yoke and the interpole whereby the reluctance was made about three times that of the ordinary interpole. These have given the 60-cycle convertor approximately three times the momentary overload commutating-capacity without flash-over that it had without their use.*

While American engineers forged ahead with the development of the higher-frequency rotary convertor, European engineers, apparently obsessed with the 25-cycle superstition and not having had such a good start in the matter of low-frequency power supply, adopted in 1902 La Cour's cascade convertor and proceeded more slowly than the American engineers with the design of the higher-frequency rotary convertor.

Another important stage in the development of the electric motor was reached when the attention of the engineer was turned to the problem of inventing an alternating-current motor with variable-speed characteristics, and it was solved by the adoption of the commutator. It was from two aspects that this type was bound sooner or later to suggest itself. Firstly because it was obvious that the direct-current series motor would, from its very nature, be subjected to the same kind of driving torque when operated either from a.c. or d.c. supply mains. Secondly, a closed coil of wire carrying an alternating current when suitably arranged in a magnetic field of the same frequency is acted upon by a driving torque, provided the phase angle between the flux threading the coil and the current is not of quadrature value and the plane of the coil is not in line with the direction of the magnetic field. This again suggests the use of the commutator, but with short-circuited brushes; that is, it suggests the repulsion motor.

In the early stage of their development two main difficulties soon presented themselves, namely (1) the inductance of the machine caused it to have a low power factor, and (2) the armature coils short-circuited by the brushes had heavy currents induced in them, especially at starting. Excessive heating was thereby produced at the commutator and subsequent sparking ensued, which diminished as the speed increased. These serious difficulties were shortly overcome to a sufficient extent by suitably disposed compensating windings. Important modifications followed, chiefly in the repulsion type of motor, and, later, two systems of brushes as suggested by Winter, Eichberg, and Latour, were adopted.

An important modification which has been extensively used in Europe for driving textile machinery is the Deri single-phase commutator motor.† In this type the speed decreases with increasing load for each adjustment of one set of brushes with respect to a fixed set. A considerable variation of speed is therefore obtained by brush displacement, which is simpler than other methods.

The grafting of the repulsion motor upon the induction motor for starting purposes was nothing short of inspiration on the part of Dr. Arnold. Here was the squirrel-

* "Standard Handbook for Electrical Engineers," 6th edn., p. 964.
† *Elektrotechnische Zeitschrift*, 1907, vol. 28, pp. 1097 and 1128.

cage induction motor, the most robust type of all motors, hampered by its inadequate starting torque. To remedy this defect, that inevitable but obnoxious device the commutator thrust itself forward for consideration, but Arnold got rid of the bugbear of commutation by using the commutator for starting only.

The development of the single-phase commutator motor into its variety of types appears on the whole to have been a steady progression, but a remarkable feature in it was the premature application of the motor to railway electrification. Before ever one was built for the purpose, certain experts claimed that it was the ideal motor for railway electrification, as, in addition to having a good starting torque and series characteristics, it was uniquely suited for high-voltage transmission, in which only one trolley line, one collector, and but few substations of a simple nature, would be needed.

These undoubted advantages might well have warned engineers to look for disadvantages both in the motor itself and in the upkeep and cost of the supply system determined by its choice, as compared with the same features of other motors and their systems. But the advocates of the motor and its system had neglected an axiom in engineering which may be formulated thus:—The impelling force of progress in competitive industrial developments is of a differential nature and is represented by the generally small positive difference between the advantages and disadvantages belonging to its successive stages.

Other experts, however, knowing that the inherent characteristics and limitations of this motor had not been fully established, arranged themselves in opposition against these more reckless advocates, and much controversy on this matter raged between the rival factions, both in Europe and in America. Indeed, the President of this Institution in summing up one of these controversial encounters in 1906 spoke of it as an exceedingly animated discussion.*

Later the limitations of the motor and its application to railway electrification were exposed.† Those of the motor have been well expressed in a general way by the statement that for large starting torque, inherent variable speed operation, electrodynamic braking, and lightness in weight, the ideal railway motor is the direct-current series type; and the single-phase commutator series type approaches more and more closely to this ideal as the frequency for which it is designed becomes lower.

The larger weight, greater spacing, and somewhat inferior operation of the single-phase type has, in general, prohibited its use in railway electrification for supply frequencies above 25 cycles per sec., the frequency adopted in Germany and other Continental countries ranging from 15 to $16\frac{2}{3}$ cycles per sec.

As to the economic limitations of the system associated with the motor, a suitable comparison at that time was soon forthcoming. In 1912, tenders were submitted from all parts of the world for the cost of electrification both by direct current and by single-phase alternating current for the Victorian Railways, a system involving more than 300 miles of track in the neighbourhood of Melbourne. The estimates received strongly favoured the direct-current system and thus showed the unsuitability of the single-phase system for urban railways.

In the case of long-distance lines, however, provided a low-frequency supply is available, much can be said in favour of the single-phase system, but even here the unanimous verdict of international commissions has favoured the direct-current system.

One comes now to the consideration of the most important motor of all, the induction motor, which was introduced for the first time in a primitive form by W. Baily in 1879.* The outstanding advantages of the induction motor are simplicity of construction, robustness, cheapness, and nearly constant speed. Its defects are large starting currents, low inherent starting torque, low power factors at light loads, and the difficulty of obtaining for it an efficient torque/speed variation.

As might be expected, therefore, the development proceeded along the lines of eliminating as far as economically possible these inherent defects of the motor, and here again the inevitable but undesirable commutator has played an important but restricted part.

The low starting torque and large starting currents were in due time eliminated by the use of wound rotors and connected starting resistances, and this method is in general use to-day. But the added starting gear is a great sacrifice of simplicity of construction.

One must admire, then, the American engineers in particular for their determination not to make this sacrifice and for their fixed aim to develop as far as possible the squirrel-cage type along the lines of larger outputs, higher starting torques, and smaller starting currents, without too much sacrifice in efficiency and overload capacity.

This task of improving the inherent starting characteristics was begun some 37 years ago by Dobrowolsky and Boucherot, who suggested the use of multiple rotor windings, whilst Boucherot is credited with the invention of the double-wound squirrel-cage rotor in 1898. It is only in recent years, however, that the value of their work has been generally appreciated—another long lapse between discovery and application, in this case about 26 years.

This lapse may be partly accounted for by the general and very satisfactory operation of the wound rotor with resistance starter, but chiefly by the stubborn and conservative attitude of certain power supply undertakings against the use of the squirrel-cage motor in general.

A somewhat similar device capable of producing nearly the same effect as the double winding, namely a single squirrel-cage winding with deep narrow rotor bars embedded in narrow slots, was also receiving attention from Hobart in America and Punga and Raydt in Germany. This led to a further important advance by Kierstead in America in 1916† and by Rudenberg in Germany in 1918.‡ These suggested the subdivision of the deep rotor bars into two or more divisions, one above the other in the narrow slot, and it was shown that the best solution for a particular case could be determined by calculation. An interesting point remarked by Hobart was that Kierstead had predicted from mathe-

* *Journal I.E.E.*, 1906, vol. 36, p. 285.
† F. W. CARTER: "Railway Electric Traction," 1922, chap. 1.

* *Proceedings of the Physical Society of London*, 1879, vol. 3, p. 115.
† U.S. Patent No. 1188182/1916.
‡ *Elektrotechnische Zeitschrift*, 1918, vol. 39, p. 483.

matical considerations that the subdivision of the rotor bar was a much better proposition than the use of the same narrow bar without division. This, however, was scoffed at by certain experts until the tests were shown to confirm the mathematical verdict. It was, as stated, a rare case of theory preceding practice.

A further development of the induction motor resulted from the attempt to eliminate the defect of low power factor, and for this purpose various types of phase-advancing apparatus were invented and applied to the motor.

Finally the elimination of the defect arising from the need of an efficient speed variation has resulted in a variety of modifications which have given speed variation in steps. The most recent development, however, has been the 3-phase commutator induction motor fitted with Schräge mechanism, by which a smooth variation through a considerable range of speeds can be obtained. The development of this type is of interest because, of all motors, its construction and theory are the most complicated.

Its complex construction is justifiable because its purposes are complex. That its theory was found difficult is shown by the disagreements of experts, notably Hansen and Steinmetz,* concerning the effect upon the speed of the extra voltage injected into the rotor circuits, while a satisfactory theory of the motor's operation was not established until several years after its commercial application had begun.

From fractional to mighty horse-powers the induction motor generally in its simpler types permeates the world of machinery. Thousands of minute motors are in use supplied for special frequencies as high as 540 cycles per sec. Fitted with grinders these run at speeds up to 32 400 r.p.m. for grinding small bearings and ball races. Others drive centrifugal oil-separators. In 1928, American aeroplane carriers were fitted with induction motors, each rated at 22 500 h.p., and, in 1929, induction motors rated at 1 250 h.p. were installed to drive high-pressure boiler feed-pumps at 3 600 r.p.m.

The development of the synchronous motor, which now claims attention, has been mainly in size, speed, scope, and enclosure. In size it has reached outputs of 50 000 kVA, three of this rating having recently been installed near Los Angeles as rotary condensers for controlling the received voltage transmitted at 220 000 V. A rapid development of higher speeds has also taken place on account of the production of material of greater mechanical strength, at an economic price, and better design. The scope, too, of this motor is increasing, as is shown by its variety of uses; and in a number of cases it is preferred to the induction motor because of its inherent condenser action. Its condenser and inductance action have also proved necessary for transmission-line voltage control and stability when the distance of transmission exceeds about 150 miles; and in this connection it is, as applied by Baum, the one and only means whereby alternating-current energy may be transmitted economically and with good operation over long distances. It follows in consequence that, without the synchronous motor, direct-current transmission would have no rival for long-distance transmission.

Finally the development of the cooling of synchronous motors has culminated in the use of hydrogen-filled enclosures enveloping the machine, a method which later may be extended to other machines. The operation is thereby more efficient, and deterioration of insulation owing to the corona effect in high-voltage machines is prevented. Sufficient safety is guaranteed by an instrument which gives an alarm when the purity of the hydrogen falls below 91 per cent, which gives an ample margin of safety, as about 70 per cent is the explosion value. Further, the machine needs no housing and it can be erected out of doors, which is an obvious gain in the Baum system as applied to very long transmission lines. A few values dealing with synchronous motors and hydrogen-cooling are taken from a paper by P. L. Alger and given in Table 2.*

TABLE 2.

Air-cooled and Hydrogen-cooled 3-Phase Synchronous Motors (Rotary Condensers).

kVA rating	1 000	10 000	50 000
Speed, r.p.m.	1 200	900	600
Voltage	2 400 to 4 150	6 900 to 11 500	13 800
Weight, tons	3·83	35·6	165
Bearing friction, kW	0·6	7·0	50
Windage, kW (air-cooled)	6	48	200
Windage, kW (hydrogen-cooled)	0·6	4·8	20

The general development in the application of electric motors is remarkable for the preservation of the variety of types. Illustrations of this are plentiful. In 1925 there was an immense increase in the application of electric motors to steel-mill main-roll drives, and in one installation at the Bethlehem Steel Works in America three different types of motors were employed, namely synchronous, induction, and direct-current machines.†

Again much can be said in favour of the electric propulsion of ships. Here, also, one finds a variety of motors in use: direct-current, synchronous, and induction motors.

In railway electrification, where some unification might have been expected to develop, there is an even greater variety of types of motors employed.

This survival of the different types of electric motors is of interest and may be explained by the fact that each

* *Journal of the American I.E.E.*, 1923, vol. 42, p. 1321.

* *Transactions of the American I.E.E.*, 1928, vol. 47, p. 125.
† *General Electric Review*, 1927, vol. 30, p. 27.

motor has a unique advantage for a given service, and some prohibitive limitations for a different service. Thus, in Northern Italy, with its extreme ascents and descents, the 3-phase induction motor was selected for its robustness, simplicity of construction, and inherent regenerative braking. In Germany the advantages of single-phase transmission resulted in the choice of the single-phase commutator motor, notwithstanding its limitations, the necessity of a low-frequency supply, and the difficulty of arranging for dynamic braking. In America every possible type was chosen and tried out, and of these the complicated Alexanderson's split-phase convertor system is worth special attention. It gave the advantage of single-phase transmission at 50 or 60 cycles per sec., combined with the regenerative braking of the 3-phase induction motor, and was first employed in 1915 on the Norfolk and Western Railway, America. Here the freightage was heavy and the gradients severe, but so successful was this method that, later, more powerful locomotives with similar equipment were built and were used to handle what is stated to be the heaviest coal transport in the world. Along the same lines and for the same purpose a similar system has now been developed, namely the Kando convertor system, which is simpler in construction and more practical in design. It was first tested in 1932 and is now in regular service on the most important traffic artery in Hungary, the line having a track length of 190 km, along which only four substations are required. It may be stated from the results of the tests and the subsequent service that the Kando system is an important development in the field of electric (railway) traction.*

It must not be thought, however, that in the increasing application of alternating-current motors the direct-current motor is losing ground. This is by no means the case. The choice of these is made for certain heavy industrial duties, for tramways and for railway traction, as a part machine in printing and hoisting sets, and for ship propulsion. Not only are the series and compound types extensively used, but the shunt motor* has also a useful field of operation.

As to the secondary developments, already hinted at, arising from the main development of electric motors, the needs of the latter, in common with those of other machines, to meet the severe limitations of economy of production, the use of higher speeds, higher voltages, and the exacting requirements of many varied services, have resulted in the manufacture of materials of better mechanical and electrical qualities.

Specialized machinery and apparatus, new metallurgical processes, precision instruments, and more exacting testing, more representative rules and regulations relating to the safety of operators and machinery, are some of the secondary developments which partially, and in some cases perhaps somewhat indirectly, have resulted from the development of the electric motor.

With the thermal limit in general deciding the rating of the motor, the continued improvements in methods of ventilation have also had an important influence on its development.

The effect of higher speeds in reducing the weight of an electric motor of fixed rating is well shown by the results set out in Table 3.

TABLE 3.

Speed and Weight of 10-h.p. 440-volt Direct-Current Motors.

1934	Speed, r.p.m.	450	750	1 000	1 500	2 000
	Weight, lb.	1 100	770	490	362	306
1920	Speed, r.p.m.	450	750	1 000	1 500	2 000
	Weight, lb.	1 650	1 050	755	570	570

The development in the manufacture of electric motors involving the factors of design, material, and ventilation, is illustrated by the results given in Table 4 for an induction-motor rating. These show how great has been the reduction of weight during the last 24 years.

The development of tramway motors for the same period is also strikingly shown by Table 5. This shows the considerable advance which has been made during the last 24 years in the continuous horse-power per ton of total weight. Further, it may be said that the improvement in the 1-hour horse-power per ton is in general due almost entirely to the use of higher speeds,

TABLE 4.

Development in Weight-reduction of 3-h.p. 1 425-r.p.m., 420-volt, 50-cycle, 3-phase Induction Motor.

Year	1910	1919	1924	1929	1934
Weight of iron (lb.)	79	59	56	53	44
Weight of copper (lb.)	19	20·5	16	18·7	12·5
Total weight of motor (lb.)	210	182	139	110	87

* "The Electrification of the Railway Line Budapest to Hegyeshalon on the Kando Phase Convertor System," October, 1932. (Athenaeum Co., Budapest.)

* *G.E.C. Journal*, 1934, vol. 5, p. 153.

combined with greater gear reduction; whilst the increase in the continuous horse-power per ton is mainly due to these factors and to a less extent to improved ventilation.

This reduction of motor weight has aided the development of all forms of electric propulsion, enabling higher accelerations, easier braking, and greater speeds, to be attained. These improved qualities, together with greater climbing capacity, have been of considerable importance in the development of the battery vehicle, which is being increasingly employed. The most recent stage, however, in the development of traction motors and vehicle motors has been the use of the highest-grade metals with asbestos and mica insulation. Owing to their excellent qualities, and by permitting a higher thermal limit, these have brought about a further reduction in the weight and spacing of the motor, while increasing its reliability and giving it a longer life.

A final question now arises concerning the development of the electric motor. Will it persist along the present lines, or is there a possibility of even a remote departure from them?

Rotation is an ideal motion for most purposes: it economizes space, it lends itself to cam gadgets and wheel gearing, and by links it can produce motion of translation. One cannot imagine the production of a more uniform peripheral driving torque than that given by the present-day electric motor. If the magnetic force on a conductor carrying a current acted in line with the operating pole instead of at right angles to it as in the case of an electrostatically charged conductor and a neighbouring charge, the form of the motor would have been cumbersome and its operation probably reciprocating.

Further, notwithstanding the variety of electric motors, a common principle governs their operation and, in general, their driving power may be represented by the product of the motor e.m.f. and a current in phase opposition to it.

It is difficult to imagine a more perfect torque-speed operation than that given by a d.c. series motor, or a more constant-speed operation than that of the 3-phase synchronous motor, yet the former has a complicated commutator and the latter an exciter.

The complexity associated with the d.c. motor is further increased when the motor is viewed as part of the usual system consisting of a prime-mover, a direct-current generator, and then the motor. Two commutators are thereby involved. Even in the exciter of the a.c. generator plant supplying the synchronous motor a small commutator intrudes itself.

The simplest of all motors is the *shaded* pole type, which is used commercially as the chief feature in certain protective relays and measuring instruments. It is simply a laminated electromagnet with an air-gap and a copper band encircling half the laminations for a short distance from one pole-face. A metal disc mounted on a spindle projects into the gap and begins to rotate with a good starting torque on application of a single-phase voltage to the exciting coil.

The simplicity of the construction is impressive—no starting devices, no commutator, not even the brushes of the Faraday disc motor. Such simplicity is viewed by the engineer with suspicion; it must surely hide many defects. Three are at once obvious—the peripheral torque on the disc is not uniform, its power factor would be necessarily low, whilst its driving power would be small. These defects could be largely removed by sacrificing some of its simplicity, i.e. by using more poles, multiple discs on the same shaft, and a condenser. Thus for multiple purposes a complicated machine appears absolutely necessary, but the engineer has to work out the minimum complexity for each particular case. This has been done in the 3-phase commutator induction motor, by the incorporation in itself of the commutator and its winding.

From time to time different attempts have been hopefully made to construct a commutatorless direct-current motor, but the models have failed to rotate; an oversight has been made in applying the laws of electromagnetic induction. True, a radial magnetic field and a single conductor or its equivalent might be used, but though manufactured in the form of the homopolar generator its limitations would prohibit any serious use of such a type.

The threading of commutation throughout most of the development of the electric motor is startling—the commutator appears to be inevitable and its removal

TABLE 5.

40-h.p., 525-volt Tramway Motors at 12 miles per hour (one-hour rating): Comparison of Weights and Ratings during their development.

Year	1910	1919	1924	1929	1934	
Continuous rating, h.p.	11·5	19	29	29	28·5	
Weight of armature and field windings, lb.	300	230	225	200	175	
Weight of bare motor, lb.	2 000	1 900	1 610	1 570	1 370	
Weight of motor complete with gearing, lb.	2 350	2 250	1 975	1 800	1 600	
Speed at 1-hour rating, r.p.m.	540	620	670	720	810	
Gear ratio for 12 m.p.h. with 32-in. wheel	68/16	67/14	73/14	75/13	75/12	82/13
Diametrical pitch of gearing	3	3	3·5	3·5	3·5	3·75
1-hour h.p. per ton of total weight	38	40	47	50	56	
Continuous h.p. per ton of total weight	11	19	34	36	40	

introduces other complexities. In single-phase railway electrification the commutator as a primary member has been successfully ousted by the complicated split-phase convertor method and by the somewhat less-complicated Kando convertor system, with the added advantage of operation not being limited to low frequencies.

Perhaps, however, the most revolutionary attempt at eliminating the orthodox type of commutator was made recently by the introduction of thyratrons as a substitute. Tests were made last year by Willis on a machine built like a synchronous motor, and thyratrons suitably connected operated as a commutator.*

Engineers are told of the enormous potential energy stored in atoms, and that the atomic energy of a drop of oil, if properly utilized, could drive the electric motors of a large liner across the Atlantic and back. This may be so, but one finds it difficult to imagine how this energy, if available, could be practically arranged to operate in less-complex material paths than the electrons have to do in the present types of electric motors.

In conclusion it may be said that, under the stress and strain of competitive forces and the imposition of varied requirements, the electric motor has been brought by engineers, metallurgists, manufacturers, and others, to near the climax of practical perfection, and there appears to be no indication that any radical departure from existing types will occur in the immediate future. Later, changes may materialize in commutating processes, through the medium of the ever-versatile thermionic valve or cell along the lines suggested by the thyratron commutator. It therefore behoves the young engineer at times to detach his mind from the present forms of electric motors and, equipped with modern knowledge and methods, use his brain and imagination to search out new lines of development.

Finally the author would like to thank the staff of the British Thomson-Houston Co., Ltd., for supplying him with the data set out in Tables 3, 4, and 5.

* *General Electric Review*, 1933, vol. 36, p. 76.

HAMPSHIRE SUB-CENTRE: CHAIRMAN'S ADDRESS

By P. G. SPARY, M.Eng., B.Sc., Member.

(*Address delivered at* SOUTHAMPTON, *10th October*, 1934.)

In 1818, one year before Oersted discovered that an electric current flowing along a wire gave rise to a magnetic field in the surrounding medium, the Institution of Civil Engineers was founded "for the general advancement of mechanical knowledge and more particularly for promoting that species of knowledge which constitutes the profession of a Civil Engineer, being the art of directing the great sources of power in nature for the use and convenience of man." The term "civil" was here used as opposed to "military" service. This is the oldest of the professional engineering institutions and can almost be looked upon as the parent of them.

In 1871, 53 years later, and 40 years after Faraday discovered the principles of electromagnetic induction, our own Institution was founded as the Society of Telegraph Engineers, becoming in 1880 the Society of Telegraph Engineers and Electricians, and in 1888 the Institution of Electrical Engineers. Its aims are the same as those of the Institution of Civil Engineers, except that they are confined to the exploration and advancement of the electrical forces of nature.

The rapid advance of applied electricity during the 63 years since the Institution came into being is very well known and it is now the basic factor in everyday life. It cannot, however, be expected that this rapid rate of development will continue indefinitely; in fact quiescent periods are very desirable as they provide time for assimilating and developing more perfectly the discoveries available. In this direction much remains to be done before the present advantages of electricity are universally adopted.

TRAINING OF ELECTRICAL ENGINEERS.

When one considers the modern advancements in applied electricity it seems that the normal technical training course for electrical engineers could, with advantage, be revised and somewhat remodelled, and, as one who is solely occupied with this side of electrical work, I should like to put before you this evening some comments and suggestions upon this important work.

First, the number of young men who now obtain engineering degrees each year is very large, e.g. London University alone produces about 140 external engineering graduates, and this is only one of many similar university institutions. The net result of this annual influx of graduates into the engineering professions must mean:—

(1) That the educational status of the rank and file of engineering assistants is rapidly rising.

(2) That it is essential that present-day students who aspire to become anything at all in engineering work must strive to obtain a good degree qualification.

(3) A large proportion of engineering graduates will have to be content with posts where advancement and remuneration have definite limits.

The raising of technical status in general should, however, eventually raise the general rate of remuneration for ordinary positions. It is interesting to note in this connection that the converse to this holds—one association in particular which has for its main object the fair remuneration of electrical engineering assistants, at the same time strives by its technical propaganda to improve their technical status.

My immediate predecessor gave a most complete and excellent survey of the various possible ways of training now available by both day and evening classes for students taking up electrical engineering work. In this address I should like to confine my remarks and criticism to certain aspects of important interest in this general training work under the headings of (1) the student, (2) the examination, and (3) general student facilities.

The Student.

In order to read for a degree the student must be at least 16 years old and have passed a matriculation examination. As this examination is a general one for admission to university study, it has a very wide scope and it frequently happens that the subjects chosen for it are totally unsuitable for the course which follows. One could, for example, take elementary mathematics, English, history, geography, and French, for this examination—an excellent example of a very bad selection. A similarly unsatisfactory choice could be made if exemption were gained on a school leaving examination.

As the normal degree course is of three years' duration and during that time an intermediate and final examination has to be passed, a preparation such as the above would make it practically impossible for a student to gain success in this time.

Now a student has only completed one side of his training when his college course closes. The remainder has to be obtained from works experience, and it is therefore very important that delays in the technical side should be as few as possible, otherwise it becomes very late before he is established in his career. A young man reading for engineering, therefore, should be properly prepared at an early school period, and trigonometry, mechanics, and general science, at least, should be compulsory subjects of his school curriculum.

Another difficulty to be frequently faced is the case of the student who dislikes mathematics. It is absolutely essential that those who wish to become electrical engineers should achieve a reasonable working knowledge

of mathematics and develop it as much as possible. It is not given to everyone to be a mathematician, but anyone with a practical mind can, with persistent application and continuous exercise, become sufficiently adept with the mathematics commonly employed in engineering. Those who approach engineering studies with mathematical limitations make their general success a doubtful issue. In alternating-current theory to-day, for example, the application of complex quantities to the solution of all circuit and machine problems is becoming universal. This is a good example of what I have just said. These processes are in the main not difficult to grasp, but their use saves an enormous amount of time and gives a much clearer vision of facts than the older and more cumbersome methods.

Consider now the student himself. There is a great tendency nowadays for students to become slovenly in their work—unfortunately this habit is frequently developed in secondary schools. There is a general feeling that it does not matter how one presents work so long as a right result is obtained or an approximately correct calculation achieved. This is an absolutely erroneous idea. Decently prepared work, results carefully drawn up, diagrams (particularly circuit diagrams) well executed, denote a careful, methodical worker, and these accomplishments will be most useful in later life. The idea that "anything will do" is not the best pivot upon which to base one's general procedure. It is, of course, a well-known fact that in some circles the more illegible and untidy a person's work is, the cleverer he is assumed to be, but from experience I am sure this is a fallacy. A student should always take a pride in doing his work in a decent way, and this tidy habit can be easily acquired without wasting valuable time on unnecessary refinements. I stress this point because in the case of external examinations, where a student is known only by a number, careless and untidy work may lead to his entire undoing.

The present system of examinations tends to promote a gambling spirit on the part of the student, and in certain cases upon the part of the instructor. Where an extensive syllabus is defined and a limited time available there is a great temptation to leave out certain sections in the hope that as no questions have appeared in previous examination papers in these sections, none is likely to appear. Students have been known to examine questions for as many years past as they can obtain papers and attempt, from careful study of these compiled lists, to forecast the probable questions they are likely to be called upon to deal with and so concentrate efforts upon these rather than upon general work. In other words, they critically examine each section of work attempted to see whether it is really essential that they should study it. This compiling of questions is perhaps permissible for revision just before an examination, but it is not the best way to study a subject during a course.

This attitude is really based upon the idea very prevalent among students, viz. that the mere passing of the final examination is the be-all and end-all of their college work. As a result of this idea where the choice of subjects for degree is varied, subjects are frequently chosen not because they form excellent backgrounds for the main branch of engineering selected but because they are the easiest to deal with and are more likely to gain a pass. This argument is followed up by the assumption that in after life one will only have to turn to reference works for detailed solutions of all practical difficulties met with.

This of course is quite wrong. Unless a man has developed a student mind and attitude during his college course, he has missed the one great point in his training and will generally find that, however excellent his reference works are, he will be able to make little or no practical use of them when he needs them later.

The saying "once a student, always a student" is a very true one. A real student will delight in tackling difficulties encountered either during his training period or in after life, without necessarily thinking of the financial rewards his efforts are likely to gain for him. I am reminded of a verse in the old college song of Sheffield University bearing upon this. It runs:—

> "There's a joy that descends on the student alone
> When he conquers a poser and feels himself grown,
> When he sees a bit deeper in nature and man
> And thinks a bit harder than simple folk can."

The man entering the electrical engineering profession is embarking upon a most interesting and fascinating course, and the attitude he adopts towards his studies will automatically settle the degree of satisfaction he will get out of life later on.

A student's life is a very strenuous one if carried out conscientiously. He is supposed to enter into college sports activities, join debating societies, attend social events, and in general identify himself as much as possible with the corporate life of his college, in addition to devoting time to his studies. This, of course, is highly desirable. He is at an age when interchange of ideas is extremely beneficial to him, and many friendships are developed in this way which frequently last for the whole of his after-life.

However, as the modern university institutions insist upon compulsory attendance for a student at all lectures and laboratory classes connected with his course, it clearly shows that he must be a hard worker and a hard player, and be prepared to keep late hours, if he wishes to obtain the maximum benefit from his college career.

If a student were to look upon his college period as an investment, then it is fairly clear that a sensible man would do all in his power to make that investment pay as good a dividend as possible afterwards.

The Examination.

Those who are engaged in technical training know that frequently the preparation for a qualifying examination and the preparation for an after career differ considerably. Actually what does the passing of an examination really mean? In its present form it simply means that on a certain day at a certain place the examinee produces a certain amount of knowledge on a certain subject in a certain time. Whether the knowledge is lasting or whether it really bears upon what is required of the student in future work does not come into the question at all.

However well-read such a paper examination may show a student to be, it is unfortunate that his prowess is, in the case of external examinations, judged on this attempt alone. In connection with this point it is interesting to note that, in and after 1936, the London University authorities intend students to submit, at the time they are examined in their separate subjects, note-books of practical work done during their training, and failure to produce such work will prevent a student from obtaining a degree. This is certainly a step in the right direction, although it does not appear as yet how this work will be assessed. Doubtless a satisfactory system will evolve in time. The scheme should in many cases result in great improvement of the work done by a student during his course.

When the details of final degree examinations are considered, certain criticisms can well be raised: first on curriculum, and secondly on examination questions. In connection with the curriculum one finds that the degree examination may require five or six subjects to be taken, some of which have a considerable amount of common ground. The result of this is that similar questions may appear in these common subjects, and when such conditions occur the result is to tend to limit the investigation of the student's knowledge in these cases. This more particularly refers to those students who take all these common subjects in the examination; those only taking one are not quite so limited.

Again, it would seem desirable that a definite course of subjects should be fixed for the three branches of engineering—civil, electrical and mechanical—and that the choice of subject available for any particular branch should be definitely limited. In this direction it would appear to be very desirable to have a universal standard of courses for these branches, generally accepted by all University institutions alike. There is much to be said in favour of such an arrangement, but whether it is practicable is another matter.

If one critically examines questions set, one frequently finds that the given syllabus is not adequately covered. Also, some of the descriptive questions set are sometimes very misleading; for to answer some of them fully would take too much time, and if he answered them cursorily the student might easily lose considerable marks and give a poor impression of his abilities. Again, spectacular questions may be set which, whilst looking important, do not involve any very serious principle, and finally the examiner may tend to emphasize a certain section of the syllabus on account of the fact that it is a section in which he is specially interested.

These general comments would seem to indicate that the present examinations leave much to be desired. On the other hand it is practically impossible to find a satisfactory alternative to this method of testing a student's capabilities at the close of his academic training. There are, however, certain ways in which the present system could be improved upon which should, to a certain extent, reduce some of the objections enumerated and make the whole training of students more satisfactory. Assuming, therefore, that the present order of examination remains, i.e. Matriculation, Intermediate, and Final, the following are some constructive suggestions.

(1) Matriculation for engineering degrees should contain the compulsory subjects mentioned previously. This would ensure a student having a groundwork of general mathematics and science before starting on intermediate work, and is a most important point.

(2) The usual intermediate examination is, apart from engineering drawing, essentially an examination that could be obtained at school, either through a Higher School Certificate or through the intermediate examination itself. There is much to be said for getting this examination over at school under school discipline, especially as there is a great tendency to keep boys at school until 17 or 18, and it would therefore be of the utmost value if engineering drawing were made a possible subject in all schools likely to supply candidates for the engineering profession. This would allow a student to stay at school until he had reached, say, 18 years of age, thereby obtaining the advantages such senior boys enjoy without crippling his after course of study. It would also allow him, if a scholarship holder, to devote three years to his final, essentially engineering, work, which would be an excellent advantage.

(3) The final examination could well be modified in the following manner. For a first degree it is essential that fundamental general principles be thoroughly dealt with—an electrical engineer should have some knowledge of subjects other than his own. Applied thermodynamics and strength of materials are two important ones. Similarly a mechanical engineer should have a certain knowledge of electrical matters, and even a civil engineer should be reasonably acquainted with electrical work.

By a suitable arrangement the main general electrical requirements could be arranged under the title, say, of "General Principles of Electrical Engineering"—this could be arranged in possibly three grades. The electrical engineer would be compelled to take all three, the mechanical engineer, say, two, and the civil engineer one. This would deal with principles alone, and the final examinations would so exhaust the syllabus that there would be no loophole for a student to pass who had not a good grasp of these essential basic facts. Descriptive questions would be practically absent, the subject being such as to require mathematical solutions in nearly all cases. In such a subject the examination might well contain a number of questions with no limit as to the number to be answered. This arrangement has definite advantages, as it would tend readily to isolate the brilliant man from the remainder of the candidates.

Following this, the mechanical and civil students would take a course which would give a brief survey of general practical applications. This could easily be covered under one subject with a minimum number of lectures, giving these students more time available for their own special branches of engineering.

The electrical student would have to deal with his application under selected groups, e.g. electrical machinery, measurements, power, etc., but these examinations would be confined to questions on these applications only and would not include any fundamental principles. Descriptive questions would be more likely to occur in certain cases.

In this scheme these sections would be much more

limited in scope than at present and the time spent on them reduced, the major portion of the students' time being devoted to the general principles. It does sometimes occur to one that an attempt is made in the present arrangement to deal with much specialized matter which the student may never be called upon to use in his subsequent career, sacrificing real groundwork thereby. Fundamental principles are, however, always cropping up when special problems have to be dealt with.

These remarks are, of course, general suggestions—very great care would be required in working out the specific details of syllabuses for such an arrangement of subjects, but it could quite easily be done.

As mentioned previously, the courses would be mapped out under the titles of Civil, Mechanical, and Electrical, and this would ensure a standard training for each branch. At present it is possible with the London syllabus for a student to take electrical power without electrical technology (it would not be a usual selection, of course, but it is a possible one).

Such a training as that indicated would give a student a very thorough groundwork of essentials, with a much more limited range of applications. He would be better prepared to tackle problems arising in his future career, because so many difficulties need first principles for their solution, and also a good knowledge of the limitations which are necessary to apply to some of the fundamental assumptions in electrical engineering. This is an important point.

Another important and very desirable change would be to arrange for the electrical student to have a much closer connection with the pure physicist. So many of the modern developments are applications of recent physical knowledge that it would appear desirable to re-cement the old connection of physics and electrical engineering on a slightly different basis. A course in modern electrical theory from the pure science side with an examination would form a very suitable additional subject in the first degree.

Whether it is desirable or not to add some course of general economics for degree qualification is a question which needs careful consideration. That such knowledge is extremely useful there is no doubt, but it might well come as a post-graduate course of instruction in, say, an evening session.

General Student Facilities.

There are a great number of excellent textbooks available at the present day, but unfortunately they are not as a general rule within reach of a student's purse. Good library facilities for colleges are essential. Many of these books are written by specialists on sections of a subject and, representing as they do the latest position of the section, form most valuable reference works to which students should be able to apply, to amplify any branch of the subject they are studying. It is important that they should be encouraged to develop the reference habit. This and the regular perusal of the ordinary electrical periodicals should form a definite part of a student's routine work at college.

One difficulty which arises in teaching is due to the fact that, as so much has to be dealt with in so short a time, students are liable to suffer from "mental indigestion." Time is a great factor in the process of assimilating knowledge. Especially is this time required by the ordinary engineering student when dealing with alternating-current work. Also time must be available for tutorial work if a proper grasp of principles is to be obtained; it is only by working out examples himself that a student is able to understand to the full his theoretical work. This is considered so important in my department that tutorial work is being introduced where our times are limited by somewhat reducing laboratory periods—the two kinds of work being considered of equal importance.

For the ordinary engineering graduate, whether he be an honours man or not, his college career should usually close on the completion of his degree. He should then obtain his works training as soon as possible, even if he returns to college later, either as a research student in some problem in which he is specially interested, or eventually, after a reasonable works experience, as a teacher.

Only in exceptional circumstances is it desirable to carry out post-graduate work immediately after a first degree. The conditions, environments, and so on, must be specially suitable in order for this course to be of value to him.

These remarks apply to the ordinary electrical engineering student taking a day course for a degree. The genius is a man apart; he soars upwards despite sometimes his apparent lack of certain knowledge, and "feels in his bones" that which the ordinary man requires much mental effort to grasp.

These comments do not apply to any great extent to those whom one might call "physicist engineers"—modern requirement and opportunities depend to a very great extent on the help of the pure physicist. The work done in many of the great research laboratories by honours physics graduates is a witness to this fact, and large numbers of these men become important members of the electrical engineering profession and our own Institution—in fact one can reasonably say that it is from this class that most of our wireless engineers are recruited.

No mention has been made of evening students—for these men the limited time at their disposal makes technical training very strenuous indeed, and this drawback is frequently coupled with that of very poor preparation. Work in evening classes has to be carried out along very narrow lines, and, although National Certificate courses have done much to provide incentives for these men, much still remains to be tackled. There is one fact in connection with this—the man who is successful on evening work alone is a man with real grit and perseverance, and the height that he reaches is well and hardly earned, for "while others slept" he has in real fact "toiled upwards through the night."

There is another point. With the general advance of electrical work the rank and file of its tradesmen will have to improve, and here it is quite clear that trade apprentices should avail themselves of the National Certificate courses now conducted at nearly all technical instruction centres. The limit set by the ordinary National Certificate course should be within the reach

of all such students—a much smaller number only would be suitable for Higher National Certificate work.

THE FUTURE OF ELECTRICAL ENGINEERING.

The outlook for the electrical engineering profession is very good—great advances have been made to improve the status of its members. The fact that corporate members of our Institution are now Chartered Electrical Engineers has added considerable dignity to the practising electrical engineer, and the time is rapidly approaching when positions of responsibility will be available for such corporate members alone—this, of course, is only right.

Many are the problems to be tackled in the future; some are economic, others scientific. The completion of the Grid Scheme must now be followed by a systematic building up of load for it. Rural areas must be developed and prices in these areas very much reduced before the full advantages of the grid are realized.

Problems connected with the operation of the grid, such as prevention of interruption of sections, must be overcome. The old battle of alternating versus direct current may possibly be re-fought in the light of modern advance in rectifiers, and many other problems will crop up for solution as time goes on.

We are living in an electrical age. The turning of a knob is the means of bringing music and speech into the humblest home from any portion of the world. A small switch is closed and the mightiest liner ever constructed slides gently and gracefully from the stocks on which she has been built into the water: such examples can be multiplied indefinitely. The electrical engineer has done more than anyone else to ease the burdens, improve the health, and increase the leisure hours, of the ordinary citizen of to-day.

It cannot be said, however, that the general community is very electrically-minded on the whole. All modern improvements are taken for granted and it is surprising what an extraordinary amount of ignorance is prevalent with regard to the simplest and common everyday electrical appliances.

A correspondent in a recent copy of *Electrical Engineering*, the monthly organ of the American Institute of Electrical Engineers, suggested that an engineering education was the ideal course for preparing the non-engineering graduate to live in the present age and to build up a greater appreciation for the engineer and his profession. Whilst this suggestion seems very drastic and impossible of achievement, it might well be argued that the time has come when all scholars, boys and girls alike, in primary and secondary schools should have included in their courses elementary and essential scientific facts, thus preparing them to use and appreciate the many engineering privileges of the day.

In the nineteenth century the best background for general education was supposed to be the classical one, but now we are fast approaching the time when the best general education will be the scientific one.

Be this as it may, the young electrical engineer, with the glorious traditions of the past behind him, may go forward in the full and earnest hope of a splendid and useful career stretching out before him.

DUNDEE SUB-CENTRE: CHAIRMAN'S ADDRESS

By J. S. LILLY, Associate Member.

(ABSTRACT *of Address delivered at* DUNDEE, 11*th October*, 1934.)

In delivering an Address such as this it is usual to take a subject which will not only be of interest, but connected with the work in which the speaker is engaged, and for this reason I am taking the general experiences I have had during recent years in the inspection of electrical plants of all kinds.

The most recent difficulties I have come across are connected with the change-over from d.c. to a.c. supply, and since the grid was extended to the Dundee area.

The most expensive trouble I have dealt with since the grid commenced operations was caused by the presence of the 5th harmonic in the system. Two condensers were involved, the smaller unit of 65 kVA capacity burning out a few months after the grid supply became general. This unit was rebuilt with an improved type of element, and although overloaded at times afterwards it still gives satisfaction.

The second condenser, of 153 kVA capacity, burnt out after most of the harmonic difficulties were eliminated on the grid, and I mention this especially to show that although severely overloaded on occasions when the current increase was reported to be in the neighbourhood of 40 per cent overload, corresponding to an 8 per cent amplitude of the 5th harmonic, the unit stood up to these conditions for a time. Both cases were supplied through an auto-transformer at 600 volts, but the larger unit was reconnected direct to the 440-volt busbars after the failure, and the auto-transformer was dispensed with.

The new capacity of the condenser on the 440-volt supply is now 135 kVA, according to the maker's figures. In this case also, an improved type of element was used in the re-building.

The change-over to alternating current has on the whole been very satisfactory, but in the case of some small fractional-horse-power motors difficulties have arisen which have proved somewhat difficult to surmount. I refer to the small single-phase repulsion motors. The chief troubles are connected with the brush-gear lifting device, which becomes worn. There appears to be no easy way out of the difficulty, since the ring which performs the short-circuiting and brush-lifting operations is continually in contact with the stationary parts, and rapid wear takes place between the surfaces. I have seen a 1-h.p. repulsion motor failure caused by the rods which pass through the rotor core from the operating weights becoming buckled and bent due to rust. Within recent years small automatically-controlled refrigerating plants driven by $\frac{1}{4}$- or $\frac{1}{2}$-h.p. motors have come into general use, and the bugbear of these small units at the moment is the uncertainty of the brush-gear operating. Should the set shut down, and the brush-gear stick, the motor will stall and burn out. The replacement of the motor may not cost very much, since a new motor is usually the most satisfactory repair, but the cost of the resultant damage, which may be very heavy, may be many times that of the replacement motor, since spoilage loss must be placed against the occurrence.

We occasionally meet heavy claims for quite a trivial repair connected with a motor or switch, and it is very essential that these motors should be fairly reliable.

Bearing troubles with these small motors have not been very frequent, but it may be too early yet to give an opinion.

Some time ago we had a spate of troubles connected with the water valves of the water-cooled refrigeration units. This was possibly due to the fact that the plants were installed about the same time, and as they had the same water-supply system the wasting and corrosion of the valves would be about equal.

My considered opinion regarding these small fractional-horse-power motors is that more trouble is likely with them than with d.c. motors, due solely to the fact that in the majority of cases a d.c. motor is more accessible for cleaning and therefore minor faults are easily detected.

With regard to the larger type of a.c. motor, I have not had much recent experience of failures. I have had troubles with fractured rotor bars and short-circuiting rings, and even the so-called indestructible rotor has had to be repaired. Loose squirrel-cage windings are frequently found and are sometimes difficult to repair. On some occasions the only remedy is to replace the complete rotor.

I had a case of a 50-h.p. 3-phase motor stator core which sheared the anchoring key, as a consequence of which the core began to move round. The three stator leads ultimately held one end of the core, and the free end moved forward slightly, thus skewing all the slots. The repair was quite simple and permanent. The core plates were held at the ends by an annular ring, and it was just a question of estimating the distance of these rings, boring a hole through the yoke into the ring, and fitting a grub screw. Bearing troubles are frequently met with, and, where severe vibration is present, white metal and ball bearings will almost certainly require attention. White metal bearings will not stand pounding from spur gearing, and where this type of bearing is fitted the bearing should, where possible, be changed to the gunmetal type.

I am not in favour of ball bearings on large machines, and I have not experienced much trouble with roller bearings.

The commutator type of a.c. motor appears to give considerable satisfaction, but flash-overs have been known to occur at the slip-rings for no ascertainable reason. In the cases referred to, insulating barriers

have been fitted between the respective slip-rings and brush gear, and no further trouble has occurred since the alterations were made.

Some types of a.c. starter gear give trouble due to lack of efficient means for absorbing the force of the spring in the return operation. The shock due to the return of drum or starter radius arms is sufficient to shear the metal stop-pins provided. Rubber stops are quite efficient in most instances, but require renewal from time to time, especially in oil switchgear. In the connecting-up of oil switchgear I have found numerous instances where the erector has allowed the vulcanized-rubber cables to rest against an oily surface, or even to dip into the oil. The oil causes the rubber insulation to soften, and everything becomes very messy unless steps are taken to protect the oil from coming into contact with the rubber. I have found that taping the cable with empire tape is very effective in preventing the trouble.

I have had cases of rubber insulation softening due to the heat of the motor distilling the insulating varnish and driving off a gas which had the same effect of softening the rubber and leaving the wires inside the terminal box completely devoid of any insulating medium except the tape and cotton covering shells. In this case, also, empire tape wound round the wires protected the rubber from softening, until the effects were completely eliminated. I have also come across numerous instances where vulcanized-rubber cables were allowed to dip into the oil of oil-immersed transformers, with the result that the rubber insulation became pasty and made a mess of the terminal board, which was below the oil-level.

With regard to the application of a.c. supply to lifts, the chief objection is magnetic hum, but with the introduction of a rectifier to supply the control and brake circuits with direct current this objection is overcome, and the change is a decided advantage. Some makers fit controllers having only a one-step operation, but in the case of goods lifts, which operate at low speeds, the shocks due to rapid acceleration are too severe, and I prefer a 2- or 3-step accelerating switch in the rotor circuit.

On passenger lifts the self-levelling micro-drive system is very satisfactory and works well, but the supply engineer may not regard with very great favour the introduction of large squirrel-cage units, owing to the very heavy starting-current kicks experienced. I understand that this objection has been got over by designing a high-resistance squirrel-cage rotor.

The question of fuse protection is raised very frequently, and it is quite common to find a different size of wire on each fuse of a 3-phase motor. The fuse with the lowest rating will, of course, blow first, and if the remaining fuses are heavy enough the unit will be on single-phase and will soon burn out.

I am not in favour of some recently installed a.c. switchgear having thermal metal-strip overload trips. It is too easy for the handyman to bend back the loop of metal, which makes the arrangement quite useless as a protection. A far better arrangement is to have overload protection for running conditions, and a main fuse of ample rating in circuit for starting conditions.

My remarks may appear to some to be redundant in the case of d.c. plants, but they are still with us and may even supersede a.c. plants in some instances.

The chief troubles with d.c. plant are faulty commutator intersegmental micas and, in the case of starting switches, the radius arm. It was supposed, years ago, that pitted intersegmental micas were due wholely to built-up micas, which were in general use at that time. No doubt this was a contributory cause, since the mica was very soft. To-day, however, clear amber mica is generally used, and the same troubles are experienced. The pitting usually takes place at the edge of the brush track. The dirt or dust appears to be swept clear of the track by the brushes, and pitting takes place on the outside edge of the track of the brush.

A slight trace of oil on the commutator surface is sufficient to start the trouble, but this is not the only cause, and where the micas are undercut it is advisable to keep careful watch, otherwise a short-circuit will develop and burn out the coil connected between the bars. With a series winding, coils at opposite points will be involved and, unless prompt action is taken, a complete rewind may be necessary.

It is not advisable to undercut micas where dirt and oil are present. Although this is often done it does not help very much, as when the micas become high due to the copper wearing more quickly, flatting takes place, which necessitates skimming-up fairly frequently. However, it is better to do this than to risk a burn-out.

In a certain type of motor recently introduced, the commutator is built up on a bakelite sleeve, which cracks and allows dirt to enter, causing the armature to break down. There is no repair possible with this commutator, which must be renewed in each case.

A further trouble then arises due to lack of space, and a type of commutator built up on a metal sleeve, but with the end of the sleeve riveted to bind the commutator, has to be used. The risk of failure is lessened with this second type, but should repairs again be necessary, another new commutator is required. However, since the sleeve is of metal, the initial cracking troubles are eliminated. Taking each case on its merits, the metal sleeve makes by far the better job.

Cracking and fracturing of the bakelite type of brush box are also common, but I find that if the part of the box in contact with the frame is lined with a thin lamina of mica very little trouble takes place afterwards, since the mica is sufficiently thick to prevent a short-circuit to earth.

The majority of starter troubles are more or less due to the radius arm sticking. I should like to see a general use made of starters having the no-volt coil connected in series with a resistance, and taking the line voltage, instead of being in series with the field. The no-volt coil is then independent of the field current and ample tension can be given to the arm to return to the full-off position. At the same time the coil will have sufficient holding power.

In many cases of switchgear, and occasionally motors, the amount of space available to hold the cables entering the switch casing or terminal boxes is very limited, and it is quite common to find cables cramped into a space barely able to hold the wires, let alone make a con-

nection. Makers of plant should give more attention to this point.

Another point to which makers give very little attention in connection with starters, and probably more so in connection with motors, is the terminals themselves. I wonder how many of us have attempted to tighten a terminal nut, only to find the whole terminal move round, the only means that can be taken being to remove, say, the terminal block in a motor, which means that the leads have to be disconnected, after which an attempt must be made to make a secure fit. In certain makes of motors it seems that the terminal box is made as small as possible.

Breakdowns in connection with lifts and cranes do not appear to be quite so bad as formerly, owing probably to the work now being chiefly in the hands of specialist firms and to the parts being standardized. The general troubles with lifts are contacts and contact springs giving way owing to wear and tear. A brake may fail to act and cause an armature burn-out, and I had one case where the lift attendant filled the gear box with varnish in mistake for oil, with the result that the armature burnt out after the varnish had had time to gum up. Shunt discharge troubles from brake and motor fields were at one time a common occurrence, but I have not come across many lately.

Private house plants are now going out of use owing to the extension of public supply companies' lines, which appears in many cases to coincide with the period when these plants are ready for expensive renewals, but I think this is just a passing phase of development and in time small lighting plants will come into their own again, especially in remote country districts. Most of these old plants gave good service, and some batteries I have known were 30 years old before renewal was required.

The wiring of these old installations has given great satisfaction, and many installations I know of are over 30 years old and are still good for many years yet. The insulation of the cables is, of course, very hard and brittle, but if they are not disturbed there is no reason to be very anxious about safety conditions. However, it is advisable to have insulation tests made at regular intervals as a precaution.

This leads me to the thorny question of installation, and whether a cheap installation is as good as a more expensive one. A so-called cheap installation is to most of us, I think, very slipshod, and one which had better not be seen by practical men.

As an example of an expensive but slipshod job I should like to mention a private house installation which had been carried out with a special type of metal-covered cable. The sheathing was a sort of tin-lead, and below it a wide, thin, ribboned copper strip was wound round the vulcanized-rubber insulation. The work of installing was carried out without even a junction box being fitted, and in parts, as if to recognize the importance of sheath bonding, a small copper-wire jumper of No. 18 S.W.G. was used to bond the sections together. This wire was simply twisted round the outside of the cable and in most cases was loose. The copper strips were on occasions loosened out and bolted together by a small bolt and nut, but this was also done in a very haphazard manner. Fortunately a very minor fault occurred which brought the whole system of wiring to our notice, with a result that on our recommendations the whole plant was scrapped and the house rewired. I know of no type of wiring I am more afraid of than the lead-covered type. Very often nails are driven into the walls and into the cable, and this is one of the reasons why I object to this wiring being hidden. Even on the surface, I come across numerous instances where the cable has sagged, and in very many instances I have found the lead covering badly cracked. I have even found the cables lying adjacent to gas pipes, but this can also happen with other systems.

A lead-covered job should be entirely metal-clad throughout, and have proper nipples and glands at switches and distribution boards. If the work is done by a careful workman it should give every satisfaction. With regard to conduit systems, insufficient attention is paid to the question of drainage of very long runs, and it is conceivable that condensation may take place. The same remarks apply to vertical sections, which should have a small drainage hole fitted at the lowest point of the run. To my mind there is nothing to beat a conduit job where conditions are favourable, and we have on many occasions had tough-rubber-sheathed cables fitted in place of vulcanized-rubber cables. In a situation where the conduit cannot be continued with safety owing to damp conditions, the rubber-sheathed cable can be continued on porcelain cleats, or even on metal strips, providing approximate means are taken to make the earthing of metal fittings satisfactory to conform to reasonably good practice.

I recently had a case where tough-rubber-sheathed cable had been in use in a farmstead for about 8 years, and had deteriorated rather badly. The twin type of cable was fitted along the inside of the supporting beams and woodwork of the roofs and secured by small lead saddles. Interaction took place between the copper conductor and the lead and small holes which looked as though they had been caused by rust were formed in the insulating covering. Probably the interaction was accentuated by the ammonia from the animal manure below. The supply voltage was 275 volts (d.c.); I wonder what would have happened on a 250-volt a.c. supply.

This experience has rather destroyed my faith in the infallibility of tough-rubber-sheathed cable for all conditions, but I have since been informed by the makers of the cable that there is a special type on the market which can be depended upon to withstand even the foregoing conditions. Unfortunately, in this case, the part was rewired, presumably with the wrong type of cable.

In addition to the holes in the cables I have mentioned many cracks were observed. These were due to moisture from the animals lodging for a time on the surface, and not to any interaction of metals. I understand that troubles such as this have been reported in the Press. It is difficult to know what system to adopt for such situations, and it will be interesting to hear other views on this matter, which is rather important.

There are numerous metal-clad systems of wiring in vogue, but I will not mention these as they are all more

or less similar to the lead-covered systems, but I should like to refer to wood casing.

In factories the number of wood-casing installations I come across is surprising. This is no doubt due to the fact that the originals were wood-casing jobs, and any renewals were simply a repeat of the system. Wood casing has the advantage of effectively supporting the wires from vibration, and, providing conditions are dry, it appears to be the best system to use in certain situations.

I have seen both conduit and tough-rubber-sheathed open-type wiring used in precisely the same conditions, and the wood casing has given no trouble whatever. In the case of the conduit, troubles occur from time to time owing to screws slackening back in the ceiling roses and earthing sections, and dampness due to condensation also takes place. With the tough-rubber-sheathed system, although no trouble has yet occurred owing to vibration, the lengths of cable between the fixing cleats vibrate considerably and will in time fail from fatigue. I expect that most of my listeners have had experience of earthing and of attempts at earthing, but it is rather surprising, in view of the common knowledge of the danger of insufficient earthing, to find so many men in charge of plants who simply cannot grasp the importance of the subject.

Of appliances sold which are supposed to have an earthing connection, a paper could be written, but it will be sufficient here to take one or two examples of recent experiences.

One case was that of a small portable a.c. blower working on a 250-volt single-phase supply. The cable from the blower was a 3-core one terminating in an ordinary adaptor, but the earthing or third wire was fixed to one of the socket pins which fitted into the bayonet socket of the metal lampholder. I was informed, very positively, that this connection earthed the apparatus.

Another case was that of an electric iron in use in an infirmary laundry. The so-called earthing device was a small clip-type spring fitted on the outside of the plug for the iron; it could not possibly be depended upon to keep in good order. Earthing was especially necessary in this instance, as not only were the irons in constant use but the place had a stone floor and disused gas pipes were near. I have seen the same type of iron with a crude terminal fitted, and I find it difficult to understand why makers cannot produce a 3-pin connection.

People should be encouraged to use electricity for all purposes by having sound apparatus brought to their notice by an organization which has no axe to grind except to encourage the use of electricity.

Each case will of course depend on its merits, and it is our duty as engineers to take an interest in everything pertaining to our profession, and not to let things drift. If the demand were strong enough I think that makers of plant would be compelled to change their methods.

In all the cases to which I have referred a proper inspection service was provided. It is difficult to imagine the state of affairs where the installation has been carried out by a draper or plumber who, probably owing to dull trade, turns his hand to electrical engineering.

I have discussed the various aspects of the subject I have brought to your notice, not in the spirit of criticism, but as a real effort to focus your attention on matters which are probably only met with occasionally. We have no information as to conditions and breakdowns of plant which have no inspection services, but it is unlikely that conditions are any different from those of which we have experience. To my mind the only difference is that the faults are hidden, and it is undoubtedly only a matter of luck that keeps down the accident returns.

As regards breakdown of plant, we know that inspection services prevent failures, and for this reason it is wise to have an efficient inspection made at regular intervals, when incipient faults may be detected and remedied.

Even where faulty apparatus is concerned, this can be made comparatively safe and efficient by regular inspections, and a watch kept for possible occurrences by persons experienced in the work.

TEES-SIDE SUB-CENTRE: CHAIRMAN'S ADDRESS

By F. A. LAY, Associate Member.

"A BRIEF REVIEW OF THE EFFECTS OF ELECTRICAL ENGINEERING."

(*Address delivered at* MIDDLESBROUGH, *15th October*, 1934.)

In the many and far-reaching changes that have taken place in the world within recent years, electrical engineering, directly and indirectly, has played and is playing a predominant part, and in considering a subject for this address I thought it might be interesting briefly to review the effects electrical engineering is having on the life of the community.

One has only to consider the slow means of transport and communication, the inadequate lighting, and the lack of effectual motive power, in vogue 100 years ago, to realize the progress that has been made.

At that time electricity was regarded as presenting interesting phenomena but as being useless for practical purposes, and it was not until Cooke and Wheatstone invented the electric telegraph in 1835 that electricity was usefully employed.

Small telegraph companies were formed in various parts of the country, and these were in operation until the passing of the Telegraph Act in 1868. This act empowered the Postmaster-General to purchase the existing telegraph companies' rights and to create the telegraph system as a Government monopoly.

Now let us note the effect of this epoch-marking innovation. In business and trade the communication of orders and of business information by telegraph enabled merchants and traders readily to compare the prices of commodities in various parts of the country, and this, together with the rapid transport of goods on railways, led to prices being stabilized at their proper economic level, so greatly increasing trade and conferring on the community the benefit of cheaper goods.

The effect of the introduction of the telephone service in 1878 has been even more speedy communication.

The immediately effective call for help in cases of emergency is an obvious benefit that the telephone has conferred.

Conversation with friends at a distance has greatly added to social amenities, but perhaps the greatest usefulness of the telephone is in business where, by affording instantaneous communication of information, departmental instructions, and orders, it has led to the speeding-up of business life as perhaps no other agent has done. For instance, it is said that the New York brokers do 75 per cent of their business by telephone.

The service has grown to such proportions that at the present time almost anyone anywhere on the same continent, and sometimes on other continents, can be engaged in conversation. Again, it is the electric telegraph and telephone, together with the railway, that have enabled newspaper proprietors to place the events of yesterday before their readers at the breakfast table. In former times newspapers had contained news days and, in many instances, weeks old, and had been read by comparatively few people. After the introduction of the electric telegraph, however, the supply of cheap newspapers containing news less than a day old to some extent created its own demand, and they were purchased and read in great numbers by the general public.

On any given day the articles and editorial comment in various newspapers are a vivid reflection of the diversity of opinion on current events, and as people are usually more disposed to read views with which they are in agreement than those to which they are opposed, they are inclined to read the same newspaper day after day. By thus absorbing one general trend of thought their views tend to become more and more deeply rooted. This tendency is in contrast to the effect of the wireless broadcast, as we shall see later.

Industrially electricity has not only led to the creation of the electrical trades which employ many millions of pounds of capital and hundreds of thousands of workers, but it has been the means of fostering many others, notably the motor-car and aeroplane, the electro-chemical and electro-metallurgical industries, and the cinema.

The motor-car and aeroplane owe their inception to the electrically-fired petrol engine, so that without electricity it is extremely doubtful whether either would have been developed at all.

The cinema may not have had an electrical origin, but electricity has given us the sound film so that to the modern cinema with its talking machine a supply of electricity is indispensable.

Electricity as a motive power in factories is now so generally adopted that the great amount of persuasion that was required years ago to induce manufacturers to change from steam or gas engines to the electric drive is apt to be forgotten.

The adoption of the electric drive, and taking power from a supply authority, not only relieves the manufacturer's mind of the power problem, but the fact that it can be measured more accurately than any other form of power enables him to allocate his power costs more precisely. This specially applies where, for instance, in a machine shop a separate motor is provided for each machine. Where this industrial drive has been adopted the elimination of line-shafting and belting has added greatly to the safety of the workers engaged.

This is the machine age and it is electricity that mainly provides the motive power for driving the machines which, by mass and specialized production methods, produce goods in such quantities that markets

everywhere are flooded to such an extent that in the economic sense it would appear that the world has passed from the age of scarcity to the age of plenty.

The problem of production may for the time being be considered as having been solved. The problem that has to be faced in the future is that of the more abundant distribution of the goods and services that are so readily produced, and it is probable that electricity will play a large part in the solution of this problem.

The provision of motive power is, however, by no means the only industrial use of electricity.

The work of the electro-chemist by rendering available so many plated articles has increased the brightness and attractiveness of metal goods, and in this connection chromium plating has proved a great boon to the community on account of its non-tarnishing properties.

The introduction, early in this century, of the electrolytic process for making aluminium had the effect of reducing the price by over three-fourths. This has led to great use being made of aluminium, notably in motor-cars and aeroplanes, whilst in the domestic kitchen aluminium utensils are light to handle and attractive to use.

The electric furnaces for the production of the world's supply of calcium carbide alone require nearly half-a-million kilowatts, and when we remember that the manufacture of carborundum, amongst other commodities, is only rendered possible by the electric furnace, the important effects of electro-metallurgy become more apparent.

The utilization of the world's water-power resources on a large scale is another important industrial effect of electrical engineering. While there are still in existence some of those rustic water-wheels which afforded power to our grandfathers for driving the village mills, it is only the development of electrical machinery that has made possible the use of the world's abundant supplies of water power.

In the United States and Canada a large proportion of the electrical energy developed by the hydro-electric schemes is utilized for pulp- and paper-making and for electro-chemical and electro-metallurgical purposes.

On the Continent of Europe and in Great Britain water power is being increasingly used for generating electricity, so to some extent conserving coal supplies, and in many of the tropical dependencies of the British Empire economic development is directly interconnected with the harnessing of their water-power resources.

The greater availability of electric power during recent years has had the effect of spreading industry out from the towns into the rural areas, especially in the South of England.

The decentralization of industry has naturally been accompanied by a corresponding movement of population, and the growth of garden villages—well-equipped housing schemes in country surroundings, every house having its supply of electricity—is a valuable consequence.

Closely bound up with the decentralization of population is transport, in which electricity, directly and indirectly, plays such an important part.

The change-over of the Underground Railways of London from steam to the electric drive not only abolished the smoke nuisance underground, but by providing a quicker and healthier service of trains attracted much greater patronage by the public. This relieved surface traffic and paved the way for the great developments that have since taken place.

In practice the electrification of a surburban line does tend to increase the traffic receipts. This is probably due to the public appreciation of increased acceleration of the trains and quicker service.

When electric tramways superseded horsedrawn buses in most large towns at about the turn of the century, they provided a quick means of transport from the centres of towns to the suburbs, and so greatly aided the growth of residential areas.

In more recent years the tramway car has been replaced by the trolley-bus and the motor-bus. The latter particularly has assisted the decentralization of population by enabling urban workers to live in country surroundings.

In recent years omnibus companies have tried to compete with railways even over long distances. In this country, however, it would appear that travel by long-distance buses has passed its zenith and that public favour is returning to the railways.

In some places abroad very long-distance bus services are operating where no railways and even no roads exist, a notable example being Damascus to Teheran.

The development of the motor-car to its present state of reliability, elegance, and comfort, has been one of the outstanding achievements of this century, with a consequential improvement in roads.

As petroleum is not indigenous to this country our supplies have to be imported, but that the conversion of coal into petrol is now a commercial possibility is shown by the erection of the coal-oil plant by Imperial Chemical Industries at their works at Billingham-on-Tees.

In the healing art the use of electricity in producing X-rays has had its effect in greatly improving the diagnostic methods of physicians and surgeons. During recent years exposures in radiography have been so shortened that snapshots of any part of the body can now be taken which give far better results than were obtained by long-time exposures 25 years ago. In surgery modern X-rays will show not only fractures of bones but also tumours in any part of the body, and the rays are used by dentists for the detection of pyorrhœa. X-rays possess valuable properties in the treatment of malignant disease, and malignant cells have even been made to disappear by their means.

The successful use of diathermic currents to produce local heating even in deep-seated tissues in cases of rheumatic disorders—the Bergonic chair in bringing about rhythmic muscular contraction and relaxation without effort on the part of the patient—the use of infra-red and ultra-violet rays and sunlight lamps—are all opening up an immense field for the use of electricity in the healing art and have the further effect of decreasing the reliance of the medical profession and the lay mind on medicine as the chief means of healing diseases.

In the domestic sphere, where it has been adopted, electricity has greatly eased the burden of housework,

and those associations that are helping to foster the use of electricity by the housewife are rendering a great service to the community.

The easy portability and small heating time-lag of the electric fire, the convenience and uniform results given by electric cooking, the drudgery-saving of the electric vacuum cleaner and washing machine and the thermostatically-controlled electric hot-water supply, combined with the cleanliness of all electrical apparatus, have made possible the lightening of the drabness and drudgery of housework as perhaps no other factor in the domestic economy has done.

It is not everyone who can afford electricity in the home, and in some cities, of which Edinburgh is an example, public wash-houses—one for each area of the city—are equipped with electric washers, wringers, and centrifugal driers. Only the airing and ironing have to be done at home. These facilities are greatly appreciated by the poor people who use them.

In this way electricity has played a great part in the emancipation of woman from domestic drudgery and has made her in a more real sense the mistress of the home instead of its slave.

The domestic freedom that electricity has brought about has given the housewife and all who are engaged in domestic duties a greater realization that the home is a place to be lived in and enjoyed.

The foresight shown in the redesigning of tariffs so as to be fair to the consumers and at the same time encourage a wider use of electricity, and the reorganization and extension of systems of supply in recent years by the supply undertakings, show that the latter are alive to their duties and opportunities. But it must always be remembered that the sale of electrical goods and of electricity is a commercial proposition and that the yea or nay rests with the consumer.

As housewives are inclined to be conservative the future sale of domestic electricity might well be fostered by the supply undertakings giving special encouragement to the educational authorities to teach the use of electrical appliances in the domestic science classes.

Wireless is generally considered by the public to be the electrical marvel of the twentieth century. Its usefulness at sea is so well known that it would be superfluous to mention the lives that have been saved and the aid that has been rendered in cases of emergency after a wireless call for help.

The development that affects the public most intimately is broadcasting. During the twelve years that have elapsed since the British Broadcasting Company commenced its operations a tremendous advance has been made in the range and character of the subject matter broadcast, as well as in its technical quality and power.

In music, broadcasting may have a tendency to make people perform less themselves and to listen more, yet it has, I think, raised the standard of appreciation of and increased the demand for good music. Amongst the general public those who are players of instruments have constantly brought before them models of how instruments should be played, and so the standard of expectation amongst the musical public tends to be raised.

At the same time this high standard of excellence may either encourage amateurs to greater efforts in emulation or it may have a disheartening effect. In this connection it is sometimes difficult to believe that the electrically recorded gramophone records that one hears broadcast are not the actual performances themselves. In fact the gramophone record may give an even better rendering, for the following reason. When a record is made the musical number or song is reiterated time after time until the performers and producers are satisfied, and so a record may give a better rendering than any one single performance may do.

A great sense of humanity is spread abroad by the Sunday evening appeals, which contain all the warmth of the spoken word. These appeals bring home to us, in a way and at a time that no other agency could do, the pressing needs of and the work done by institutions of which we might otherwise hear very little.

Another important effect of broadcasting is that it enables people, through hearing their voices, to feel an intimacy with the Royal Family and with those in high authority and so to feel the human touch.

In practice it has been found that the broadcasting of church services does not materially affect church attendance and that the general public are reached by and enter into the spirit of broadcast services. As all religious denominations are allowed to broadcast, the people's religious outlook is broadened and, although their convictions may remain unchanged, a spirit of toleration is thereby fostered.

On the talks and discussions which are broadcast by the ablest exponents of their subjects many ideas may be brought to bear, and so the wits of the intelligent man are sharpened, his outlook is broadened, and his judgment is rendered more keen.

The innovation at the last General Election of broadcasting by the leaders of the three political parties enabled the public to hear and to compare their programmes in a more concise manner than ever before.

Thus by the wireless broadcast an informed public opinion is moulded, a public opinion which sees both sides of a question and is in contrast to the newspaper-fed opinion which absorbs one trend of ideas day after day.

The presentation in the cinema of the topical events of real life, of foreign travel, of the marvels of insect life, and of plays specially written for the screen, is a definite expansion of the field of art and of its exhibition to the public.

Thanks to the cinema each half of the world is learning how the other half lives.

The ability of this pictorial art to cast aside the barriers imposed by languages made it apparent at an early date that motion pictures had an international appeal. Subjects can be chosen to reach all races, classes and creeds, and to give offence to none.

The advent of sound to the screen has had a revolutionary effect on many phases of production. Electrical and acoustic engineers have become important in the studio, whilst the players have found it necessary to cultivate voice as well as movement and facial expression. The talking picture now tells its story simply and directly, and an outstanding development is in topical subjects,

which permits the recording for present and future generations of the images and voices of famous people.

The sound picture has, however, restricted the field of distribution of a film to those countries in which its language is spoken, and so it has encouraged the various countries to produce their own talking pictures.

In the development of the art of war electricity has played indirectly a very active part. Rapid communication of intelligence and orders by means of the field telegraph and telephone has led to battles on land being fought on a vastly increased scale. As the higher command behind the lines is by these means in constant communication with the battle front they are able to direct operations on a scale that would otherwise be utterly unwieldy.

At sea the movements of fleets are directed by wireless from land stations by the Lords of the Admiralty, to whom the progress and result of an engagement with the enemy are instantly known.

It is, however, in the aeroplane with its electrically-fired engine that the greatest development in warfare has taken place.

The Great War was fought in the early days of flying, and even then the warring powers made great use of the aeroplane for reconnaissance and for bombing, not only the enemy's military and naval forces but the civilian population as well. Since 1918, aeroplane flying speeds have been developed to such an extent that many strategists hold that future wars will be decided in and from the air before armies and navies have time to make contact with their enemies.

The vast scale on which modern wars are waged, together with the risk to the whole population from devastating attacks from the air, will cause civilians to be exposed to the dangers as much as the belligerents.

To the power that has command of the air the enemy's roof is his frontier.

To the individual electricity has undoubtedly been the means of bringing about an increase in real wages and a higher standard of living.

Travel facilities by motor-bus and car, cheap entertainment at the cinema, and still cheaper entertainment by the wireless broadcast, and electrical appliances in the home, are all real wealth that was not available a generation ago.

By these means home life has been unified and strengthened and strong counter-attractions to the streets have been provided.

Electricity has increased the speed of industrial and business life and of communication and travel to an almost incredible extent, but its tendency is always towards efficiency.

We hear much about the rush of modern life making people neurotic, but high-pressure living is largely the free-will choice of the individual and a matter of temperament.

Electricity is the world's most flexible and adaptable form of power and, broadly speaking, its peaceful effect everywhere is the promotion of that mental and moral growth that is summed up in the word "culture."

SHEFFIELD SUB-CENTRE: CHAIRMAN'S ADDRESS

By D. H. Davies, Associate Member.

(Abstract *of Address delivered at* Sheffield, 17*th October*, 1934.)

As it behoves every shoemaker " to stick to his last," it appears to me that the most useful subject with which I can deal in this address is the recent practice in the design, construction, and operation of plant and apparatus for the generation, distribution, and utilization of electricity from public supply systems.

In passing, it is pleasing to note that the output of electricity from public supply stations for the 9 months ending the 30th September last, showed a remarkable increase of 17 per cent over the output for the corresponding period of 1933.

Steam-Raising Plant.

It is interesting to note that the fashion of installing pulverized-fuel-fired boilers is not so prominent as it was 3 or 4 years years ago, owing to the difficulties that have arisen in dealing with the grit nuisance, which has become very serious not only in power stations situated in built-in areas, but also in those stations remote from dwelling houses and factories.

The only satisfactory method so far suggested of overcoming this nuisance on large pulverized-fuel plants is to supergrind the fuel, but this method is very costly owing to the large increase in the amount of power taken by the grinding-mills. It therefore appears that the trend is to revert to the practice which was common over 25 years ago, i.e. machine-fired boilers with tall brick chimneys to carry the waste gases and grit high into the upper air.

Boiler-furnace design appears to be fairly well established with a minimum of brickwork and with suspended arches and water-tube walls. Furnaces with water walls will run continuously up to 12 000 hours without repairs to the refractory linings.

Boiler pressures up to 600 and 750 lb. per square inch, with a total temperature of about 850° F., are becoming general, and boilers generating steam at 1 778 lb. pressure and 932° F. total temperature are now under construction. Such high pressures involve special construction, and it is gratifying to note the increasing number of orders which are being received in the Sheffield area for solid forged-steel boiler-drums to cope with these super pressures. These forged drums are generally of nickel-chrome-molybdenum steel and cost about 150 per cent more per ton than normal mild-steel drums; but owing to their better physical properties such drums weigh only about half as much as mild-steel drums for the same working pressure. The cost of superheater tubes of special steel is, however, about 10 times that of mild-steel tubes owing to the higher percentage of nickel and chromium employed.

There is a substantial increase of 9 per cent in thermal efficiency by raising the steam pressure from 200 lb. to 500 lb., and an additional increase of about 4 per cent if the pressure is raised to 1 000 lb.; but as the gain by further increasing the pressure from 1 000 lb. to 1 500 lb. is only 2 per cent, I consider that 750–1 000 lb. steam pressure is the " worth while " limit. The striving to gain that extra 1 or 2 per cent in efficiency involves greater cost of repairs and maintenance of the plant, which is often lost sight of. Extra refinements are also involved which are additional links in the chain liable to break down.

The evaporative capacity of the largest boilers recently constructed in England is in the region of 300 000 lb. per hour, but some American power plants are using boilers with capacities as high as 490 000 lb. The use of boilers of such a size appears to me to be undesirable. The motor-driven auxiliaries on these large units are many and varied, and any one of them is liable to fail at a moment's motice; and as the practice appears to be to connect one of these boilers to a 40 000–50 000 kW turbine as a complete unit, the failure of a small auxiliary would involve the loss of a substantial percentage of the station's capacity unless the station were a very large one.

These very high pressures and temperatures also involve very special water-feeding plant and other appurtenances.

Steam Turbo-Alternators.

Generating sets of the order of 50 000, 75 000, and 100 000 kW capacity are now either running or under construction. The designs accepted as most suitable are the two- and three-cylinder types, owing to the difficulties encountered in the construction of a single-cylinder machine; the last mentioned would necessitate a number of stages of expansion in order to reduce the steam velocity and increase the efficiency. The extracting of steam from the low-pressure stages has become common practice, and some of the larger plants have 4- or 5-stage feed-heating, increasing the feed temperature by as much as 200 or 250 degrees F., with an effective net reduction in heat consumption of about 11 per cent.

Many improvements have been made in blade design, the tendency now being to use special alloy steels, the blades being heavily nickel-plated after machining and finishing. Such refinements are necessary in order to deal with the high steam pressures and temperatures employed, and resuperheating the steam at an intermediate point has been adopted in order to overcome the damage caused to low-pressure blading by excessive condensation. This resuperheating has necessitated the evolution of methods to control possible excessive speed and consequent tripping-out if the load is suddenly

beautiful country villages. Wood-pole construction is "cheap and nasty," and there is no reason why, for instance, lattice-pole construction should not be used in most situations.

Reverting to the relative advantages of alternating current and direct current, it is found that many consumers obtain better results from d.c. driven machinery owing to the flexibility of the speed control, etc.

The cost of changing consumers' apparatus in a thickly-populated business area is also sometimes prohibitive. I recently had an example of this on my own system, where, owing to the growth of the load, it was found necessary either to install in the power station more converting plant and lay additional low-tension feeders or, alternatively, to change over an area in the centre of the town to alternating current. It was found that if such a change-over were made it would be necessary to install rectifiers on many consumers' installations, including hospitals, cinemas, newspaper printing-works, large stores, etc., and it was therefore decided to construct one fully-automatic rectifier substation in the centre of the area concerned and to continue to supply direct current. The actual cost was about 30 per cent of the estimated cost of changing over to alternating current, and not the slightest trouble has been experienced in the functioning of the equipment. The rectifier installed was of the glass-bulb type, which, owing to its extreme simplicity and reliability, is becoming more popular than the steel-tank type for general distribution.

Utilization.

Improvements in apparatus for utilizing electrical energy continue to multiply. Although some of you are familiar with the details of the high-frequency steel-melting furnaces recently installed in Sheffield, I will refer briefly to them. The old conception of a steelworks where men work under extremely dirty conditions must now be abandoned. The installation put into operation earlier this year in Sheffield is a model of cleanliness and precision. The high-frequency furnace has many advantages over other types, e.g. the melting of the steel without contact with contaminating influences such as furnace gases and electrodes, trouble with refractory material, and the fact that it can melt from a cold charge. The control is also much more precise.

In the field of electric lighting might be mentioned the rapid strides in the use of the gaseous discharge lamp for public lighting, which is making our roads much safer after dark. This type of lamp also has big advantages in the lighting of factories and open spaces generally. The use of neon tubes for decorative and advertising purposes continues to extend, and flood-lighting of business premises is now considered to be an essential part of their equipment.

Domestic equipment is being considerably extended by way of water-heating, refrigerating, cooking, and cleaning apparatus, and builders generally are now fitting all rooms with heating and power points, even when these are not called for by the tenants or purchasers.

The cost of installing heating plugs and air outlets in bedrooms and occasional rooms is found to be much lower than the cost of fireplaces and flues. The most satisfactory domestic electrification scheme appears to be the coal-electric one in which coal fires are fixed in the kitchen and sitting-room or lounge, with electric fires in bedrooms, bath-room, dining-room, and other occasional apartments, and a thermostatically-controlled immersion heater in the bathroom cylinder.

In my opinion the "all-electric house" enthusiast is a danger to the supply industry. Electric service will appeal to the average householder on its merit, and gradual penetration appears to me to be the much more effective method of developing the domestic electric load. Get the small gadgets in first, because it is the lady of the house who matters. If her small requirements are met first, the heavier energy-consuming apparatus will follow in good time. It is a mystery to me why consumers are so much upset by their electricity and telephone bills, when they think nothing of spending 10 times as much money on changing a wireless set or on golf, motor tyres, petrol, etc. I suppose it is because electricity and telephone services are monopolies.

WEST WALES (SWANSEA) SUB-CENTRE: CHAIRMAN'S ADDRESS

By R. G. Isaacs, M.Sc., Associate Member.

"ELECTRICAL ENGINEERING AND MODERN PHYSICS."

(Abstract *of Address delivered at* Swansea, *25th October*, 1934.)

The title "The Engineer and the Free Electron," so aptly chosen for last session's Faraday Lecture* by Mr. C. C. Paterson, was particularly significant if only as a reminder to electrical engineers that the results of modern physical research are playing an increasingly large part in our profession. The applications of Faraday's electromagnetic induction discoveries constitute such a very large part of what we know as electrical engineering that in the past a correspondingly large part of our technical education has been devoted to those applications. It is now clear, however, that an increasing amount of attention must be given to the rapidly accumulating knowledge of the behaviour of the electron. I do not presume to claim any specialized knowledge of modern physics, but some understanding of it is essential if we are to avail ourselves fully of present-day possibilities, and in this address an attempt will be made to summarize the position in so far as it already affects the work of the engineer. A few years ago this task would have been easier in that the classical model of the Rutherford atom would have been used to explain most of what we require to know. We have now to accept the fact that an atom model is no longer possible, as electrons can no longer be thought of wholly as discrete particles. In fact we have to accept the position that our material universe is, in the words of Jeans, more like a great thought than a great machine. This is discouraging to the practical man who has been brought up in a world of realities, and he generally gives up the attempt to follow science further. But must we give up our atom model? In our early efforts in the study of electricity many of us were helped by hydraulic analogies and we gradually learned to realize their limitations. In the same way the picture of the Rutherford–Bohr atom can still help us as long as we realize that words like "collisions," "shot out," and "falling," must now be used somewhat metaphorically in connection with electrons.

Modern applications of the electron theory are mainly concerned with the conduction of electricity through gases, and a study of the following experiment due to Lenard is probably the best approach to an understanding of this phenomenon. In this, a partially evacuated vessel containing a filament, grid, and plate, was used. The plate was connected to an electrometer and maintained at zero potential. The grid and the filament were both positive, the grid being the higher. As the grid voltage was increased the plate current was found to be zero until a certain critical voltage was reached. Above this there was a uniform increase of current until some higher voltage was reached, beyond which the current increased more rapidly. Careful experiment showed a number of these critical points, each gas giving rise to its own characteristic series. Closer investigation showed that at the lower critical voltages the current reaching the electrometer had not been conducted through the gas. The explanation of these results is now fairly clear. Electrons associated with any particular atom can only have certain energy states, and collisions between free electrons from the filament and gas atoms will be elastic, producing no effect on the internal energy of the atom, unless the colliding electron has sufficient velocity to raise this to the next higher permissible value. Below the first critical value no appreciable current will therefore be detected on the electrometer. If, however, the velocity is further increased a collision may increase the atomic energy to some higher value and after a finite interval of time this energy is given out in one or more steps, each in the form of a quantum of radiation having a frequency proportional to the change of energy. Each different gas has a series of critical values (known as excitation potentials) resulting in a series of radiations of different frequencies. Some of these correspond to the colours of the visible spectrum, some (of higher frequency) to the ultra-violet, while others will give infra-red or heat rays. If the colliding electron is given a velocity higher than that corresponding to the greatest of the excitation potentials an electron may be completely dislodged from the atom. The latter is therefore left positively charged and moves down the potential gradient to the plate, while the new free electron will move in the opposite direction, ready to take part in further collisions.

* See vol. 75, p. 447.

This process is called ionization and is the process by which a discharge is initiated. Further, the ionized atom can gain an electron which, as it passes through the various energy-levels to the normal level in the atom, gives rise to the emission of the characteristic radiation of the gas. This is most likely to occur with an arc discharge and with a high pressure.

Gas-Discharge Illumination.

In the experiment that has been described the conditions were idealized in order that all collisions corresponding to any one voltage should be as far as possible of the same energy. In a gas-discharge lamp the average distance between collisions is much less than the distance between the electrodes, and these conditions will not hold. In such a lamp the radiation will therefore be the sum total of millions of the various collision processes that have been described. For each vapour or gas certain energy-changes are more probable

and therefore more frequent than others, and the intensity of the corresponding radiation therefore greater. The most familiar gas discharge occurs in the neon lamp with its characteristic red radiation, but in the low-voltage, cold-cathode type the intensity of illumination is low. If, however, hot cathodes are used the characteristics are much improved. Owing to the plentiful supply of electrons there is increased ionization, a much larger current can be passed for a given size of electrode, and the voltage-drop per unit length will be much reduced, as will also the drop between the cathode and the gas. This last brings in its train a very important advantage. A high voltage-drop implies the bombardment of the cathode by high-velocity ions. If this bombardment becomes excessive, particles of the cathode are removed and sputtered as a film on the walls of the tube. This is accompanied by a reduction in the gas pressure, due to the gas being entrapped by the sputtered metal and to adsorption. Eventually a point is reached at which the pressure is too low to maintain a discharge. Hot cathodes have thus made possible a high-intensity lamp with a reasonable length of life. In some cases if the electrodes are coated with barium oxide, which readily emits electrons, they will be maintained at a sufficiently high temperature by the bombardment of the positive ions, without external heating.

What are the possibilities of these gas-discharge lamps? In filament lamps the excitation of the atoms is produced by collisions between the atoms themselves. In the majority of these collisions the slow-moving atoms will only cause a sufficient change of energy to produce heat radiation, a comparatively few only resulting in visible light radiation. In gas-discharge lamps the use of high-velocity electrons can result in a much larger proportion of collisions with sufficient energy to produce light. The result is that already lamps are being produced with an efficiency $3\frac{1}{2}$ to 4 times that of the filament lamp. The ideal for a light source would be a gas in which there was probability of a series of atomic energy-changes that would give radiation over the whole visible range, and improbability of energy-changes outside that range. The first condition is approximately satisfied for carbon dioxide, the light being almost daylight in colour, but the second condition is so far from being satisfied that this gas is very inefficient as a light producer. With sodium vapour, on the other hand, the production of light is relatively efficient but almost entirely of one wavelength. Between these two extremes there is the mercury-vapour lamp, in which all colours except red are fairly well represented, with an efficiency $2\frac{1}{2}$ times that of the filament lamp.

If two or more gases are mixed with the object of improving the colour it is generally found that the light emitted shows only the characteristics of the one having the lower excitation voltage. This is mostly due to the fact that if a gas having a lower excitation and ionization potential is added ions are more freely produced, the current increases, and, therefore, as is the characteristic of arc discharges, the voltage falls. The reduced voltage-gradient will now probably not be sufficient to produce excitation of the first gas, and the colour of the light changes to that due to the added gas.

One line of advance is to make use of the phenomenon of phosphorescence which occurs when certain substances are irradiated with light of a particular wavelength. By using a film of the substance on the inner wall of the tube there is thus a possibility of converting ultra-violet radiation into light of the colour that is missing from the radiation of the gas.

One feature of interest in connection with these lamps is that, since the apparent resistance varies with the current, the latter will not follow a sinusoidal law even though the applied voltage does. As a result the power factor is less than unity, and since this is not due to a phase displacement it cannot be corrected by the addition of wattless currents. If this form of lighting ever assumes large proportions this factor will have to be taken into account.

Photo-electricity.

Most engineers are more or less familiar with the photo-electric effect, at any rate in its "stunt" demonstration form. It is, however, generally regarded as an isolated phenomenon unrelated to other branches of their work. That this is not so can be seen from a simple experiment. If a voltage just below the value that starts the cathode glow is applied to a neon lamp, then the glow will start if the lamp is exposed to light from an arc lamp. Since light is plainly causing the extra ionization required for a discharge, that could be obtained from an increase of voltage, it would seem that we have here a collision process. Referring again to Lenard's experiment, it was stated that at the lower critical voltages the current reaching the detector did not come from the gas. The explanation now seems clear. Quanta (or photons) of light were produced by collisions, and some of these falling on the plate caused the emission of electrons, thus leaving a positive charge on the plate and the detector. So that for a photo-electric cell we require a bulb in which are two electrodes. One, the cathode, will have a large area so as to be capable of receiving as much light as possible, while the other, the anode, will be of small area. If a direct-current source be now connected to the terminals, electrons, if they are emitted from the cathode when light falls on it, will be drawn to the anode. Different materials or types of surface require different amounts of energy (called the work function) to cause the emission of an electron. But the energy of a photon is proportional to its frequency so that for each material or surface there will be a minimum frequency, called the threshold value, below which there will be no emission, however strong the light.

For most materials the energy required implies a frequency well outside the visible range, but the alkali metals show the photo-electric effect with visible light. From the foregoing it might be expected that the number of electrons released would be proportional to the number of photons that fall on the plate, i.e. to the quantity of light, and this is found to be the case so long as its quality remains unaltered. Selective emission, i.e. variation of the emission with the wavelength of the light, is very marked with alkali metals; thus potassium gives a maximum emission with blue light while with cæsium the maximum occurs where the colour is somewhere between the yellow and the green. Since photo-électricity is a surface effect, however, the

maximum emission and the wavelength at which it occurs will vary with the condition of the surface; further, if the photo-electric metal is used in the form of a thin film the results are very considerably modified. For example, if cæsium is used in this way the sensitivity is increased and occurs in the infra-red region. This type is therefore much more suitable for use with electric lamps which emit a great part of their energy in this region. The theory of selective emission appears to be still in doubt, but a comparison of selective emission curves with probability-of-excitation curves is very suggestive.

In the vacuum type of cell the current is practically independent of the applied voltage once the saturation value has been reached, and this occurs at a low value of the voltage. If a small quantity of gas is present in the cell, however, and the emitted electrons are given sufficient velocity, ionization takes place, and for every collision that results in the dislodgment of an electron we have three unit charges for one that was available before the collision and the two free electrons can each take part in further collisions. The cell in the illuminated state thus passes a considerably larger current and this current will increase with the voltage, but if too great an amplification is attempted in this way a glow discharge will start which is no longer dependent on the external illumination.

While the gas-filled cell is much more sensitive than is the vacuum type its characteristics are not so constant and there is some time-lag between the light emission and the maximum value of the current. The latest development in photo-electric cells is the rectifier type, and although this is not a gas-discharge type its general principle is so similar as to warrant its inclusion here. The cell consists of a layer of copper oxide on a copper plate, the circuit being completed through an extremely thin layer of gold or silver which has been sputtered on to the oxide. This layer is transparent and light can fall on the oxide surface. As a result, electrons will in general pass from the oxide to the metal, although a reversal of this has been noted with light of certain wavelengths. This cell has the advantage that no external e.m.f. is required and its sensitivity curve is very similar to that of the eye. It can therefore be used with a minimum of error for photometry of lamps of varying degrees of brightness. The main disadvantage of this type is that its output cannot easily be amplified, and this restricts its use. Most applications of photo-electric cells depend on the variation of current with varying illumination. These range from such applications as counting, in which the operation completely shields the cell from the light, up to its use in sound-film reproducers, in which linear response is required over a wide range of light intensity. Other applications, such as colour-matching, make use of the selective emission property in which the quality rather than the quantity of the light is varied.

Rectification.

Any device which allows electrons to pass more readily in one direction than in the reverse direction will act as a more or less perfect rectifier of alternating current, and the neon lamp may once again be used as an illustration. Owing to the dissymmetry of its electrodes, electrons pass more readily from one electrode than from the other, and if an applied alternating voltage is adjusted so that the glow discharge is just present over the surface of the disc an oscillogram will show that the current passes only during alternate half-waves. For the same reason photo-electric cells will in general act as rectifiers, although with the exception of the copper-oxide type they have too high a resistance to be of practical use. The hot-cathode diode is another familiar type, but this again has too high a resistance to allow its use except for very small currents. The ideal rectifier would be a vessel filled with gas or vapour at a low pressure and with two electrodes, one of which would emit electrons freely, producing intense ionization, and the other, the anode, of a material that would not emit electrons under the working conditions of temperature and applied electrostatic field. This ideal seems to be most nearly reached at present by using mercury vapour with a mercury cathode and a graphite anode. Mercury has a low specific heat, low boiling point, and small heat of vaporization. The mercury atom has a low ionization potential and the nucleus has a relatively large mass. Once a discharge has started and sufficient heat has been generated to cause the emission of electrons, these can ionize the vapour, and the bombardment of the cathode by the nuclei, if it is intense enough, will maintain the temperature of a portion of its surface and the discharge can continue, provided the anode is about 10 to 30 volts positive with respect to the cathode. Further, since mercury vapour can be easily condensed and returned to the cathode the latter does not become disintegrated. Graphite has a high specific heat, is relatively infusible, and does not readily emit electrons, hence its use as the anode material. The discharge is not self-starting, and the usual method is to strike an arc between the cathode and an auxiliary anode. This produces sufficient ionization to allow the main discharge to start, but even then it would only last during the half-period that the main anode was positive and would require restarting every alternate half-period. If, however, instead of one main anode, two, three, six, or more, are used having a phase difference between them, the electron discharge will continue between the cathode and whichever anode is positive to it. The multi-phase rectifier is thus virtually a commutator whose only moving part is the electron stream, and the greater the number of "commutator sections" or phases the less will be the periodic variation in the d.c. output. The foregoing simple theory is, however, incomplete as the effect of the positive ions, except as bombarders of the cathode, has been ignored. Since fast-moving electrons on their way to the anodes will continually be colliding with atoms, positive ions will always be present and will be attracted towards any anode which is negative to the cathode. These ions are in effect a reverse current and, if this is not kept very small, would initiate a discharge between adjacent anodes which would amount to a short-circuit. Fortunately the cloud of positive ions that surrounds a negative anode acts as a shield, and ions outside this zone experience very little attraction. If, however, this shield breaks down, as it would do if it were neutralized by the emission of electrons from the anode, then a discharge between anodes would be

probable. If this is to be avoided the anode temperature must be kept within a figure depending on the vapour pressure, and particular attention has to be given to the possibility of local heating.

In the foregoing the rectifier has been described as an automatic switch closing the path between an anode and the cathode whenever the former is positive to the latter, the mean d.c. voltage therefore bearing a fixed relationship to the d.c. voltage. This limitation is entirely removed if grid control is added to the rectifier. The grids, in the form of perforated sheaths or short cylinders placed in front of the anodes, will, if sufficiently negatively charged, repel electrons and thus prevent the discharge taking place until any desired point on the a.c. cycle. Once the discharge has started, a negatively charged grid is unable to control this discharge as long as the anode is positive to the cathode, but will regain control as soon as the anode ceases to be positive. This is due to the fact that the negative grid will become surrounded with positive ions which neutralize its action. The ability to control the discharge point opens up fresh possibilities in the use of the rectifier, the most obvious being that delayed discharge on each phase obviously reduces the average d.c. output voltage. Numerous methods of grid control have been devised but these can be divided into two main groups. In one the grids are kept normally negative to prevent the discharge passing, and an impulsive voltage sufficiently positive to start the discharge with certainty is applied to them at the required point on the cycle. Once the discharge has been set up it will, as has already been stated, persist as long as the anode is sufficiently positive to maintain the arc. In the other group a sinusoidal voltage is applied to the grid, the striking voltage therefore being approached gradually instead of impulsively. The latter group have the advantage of simplicity but the disadvantage that the exact striking point is less certain. In either case we have a means of smooth voltage control, entailing very small losses, that could otherwise only be obtained by the use of an induction regulator rated to carry the full load current.

Another application of grid control is as a means of high-speed switching. If the grids are given a negative bias the discharge to each anode in turn will cease as soon as its voltage falls below that required to maintain the arc, and will not restrike when the anode again becomes positive. In this way the circuit is interrupted inside the rectifier in a time less than that of one cycle and without the use of a heavy-current circuit breaker.

Yet another possibility of grid control is inversion, i.e. conversion of direct to alternating current. For this to take place the negative side of the d.c. supply is connected to the cathode and the discharge is started to each anode in turn during the first half of the negative portion of the back e.m.f. in the transformer coil. This discharge will be extinguished by the peak of the back e.m.f. exceeding the d.c. voltage and will be prevented from restarting by the normal negative bias on the grids.

It will be seen that inversion can only take place if the a.c. side is supplied with a magnetizing current from an external source, and, further, the d.c. voltage must be lower than the peak value of the back e.m.f. Inversion is, however, inherently less stable than rectification and a number of problems remain to be solved before the invertor can take its place as a standard piece of apparatus.

Conclusion.

In this address three applications dependent on atomic physics have been described. There are, of course, many others, but sufficient has been said to show the importance of the subject in our profession to-day. It may be said that the engineer has no need to understand the underlying theory of these applications. While it is true, however, that a motor attendant has no need to know the theory of the machines under his control, such a man is not entitled to describe himself as an engineer and in the long run will not perform his duties as efficiently as he would if he had that knowledge. The same reasoning applies to these new types of apparatus. Further, new devices often do not perform in service quite as they did in the laboratory, and development engineers often find difficulty in locating the trouble because the user has not sufficient knowledge of the theory of the apparatus to notice significant incidents in its life history.

Finally, it is not the business of the physicist to develop his discoveries, and if we are to reap full advantage from the rapid growth of knowledge in this branch a large number of engineers will be required with sufficient knowledge of physics to appreciate new facts and see their possible application.

In conclusion I should like to express my indebtedness to Mr. Paterson, whose Faraday Lecture inspired a considerable part of this address.

A NON-INDUCTIVE NATURAL-AIR-COOLED FOUR-TERMINAL RESISTANCE STANDARD FOR ALTERNATING CURRENTS UP TO 2 000 AMPERES.*

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[From the National Physical Laboratory.]

(*Paper received* 26*th May*, 1934.)

SUMMARY.

A four-terminal resistance standard designed to provide a voltage of 2 volts with a current of 2 000 amperes has been constructed at the National Physical Laboratory. The time-constant is $0 \cdot 1 \times 10^{-6}$, and the resistance departs by less than 1 part in 10 000 from its cold value for all currents up to 1 900 amperes. The variation with frequency up to 100 cycles per sec. is less than 1 part in 100 000.

The resistance is designed to be reasonably astatic to magnetic fields, and under ordinary conditions of use the value and time-constant are unaffected by the magnetic fields produced by other conductors in the circuit.

(1) INTRODUCTION.

In a paper published in 1930,† four-terminal resistance standards, designed to provide a voltage proportional to, and in time phase with the current passing through them, were described. These resistances provided a voltage of 2 volts at rated current, and were made for currents from 1 ampere up to 200 amperes. The cost rises rapidly with increasing current, and for currents above 200 amperes it is more economical to employ current transformers with nickel-iron cores for reducing the current to a value of about 5 amperes. This 5-ampere secondary current is then passed through a four-terminal resistance in order to obtain a voltage proportional to it. The combined errors of the current transformer and secondary resistance need not exceed a few parts in 10 000 for resistance and 2 minutes for phase angle, and it is found that when large currents are involved the phase angle of a current transformer is less affected by stray magnetic fields than the phase angle of a resistance of the best type ordinarily available. For measurements at moderately high power factors, and where an accuracy of $0 \cdot 1$ per cent is sufficient, the combination of current transformer and secondary resistance is preferable to the primary resistance, if the current exceeds about 200 amperes. A properly designed resistance has, however, the following advantages over the combination of transformer and secondary resistance, which make its use preferable for certain measurements. (*a*) The time-constant and phase angle‡ are very small.§ (*b*) The time-constant is nearly independent of the frequency. (*c*) The time-constant is independent of the current. (*d*) If reasonable precautions are taken to avoid exposing the resistance to strong magnetic fields, the time-constant is more definite than that of a current transformer. (*e*) The resistance is independent of the frequency. (*f*) The standard may be used with either direct or alternating current.

Existing resistances for large currents (1 000 amperes and upwards), however, usually have a time-constant in excess of 1×10^{-6}, and in very many cases both the time-constant and the resistance vary with frequency. A natural-air-cooled resistance standard with a nominal resistance of $0 \cdot 001$ ohm, embodying all of the above advantages, has therefore recently been designed and constructed at the National Physical Laboratory. It is capable of carrying 2 000 amperes continuously and has a time-constant of $0 \cdot 1 \times 10^{-6}$. The resistance is independent of the frequency. The time-constant decreases slowly with increasing frequency, but the change is so small that it can only be detected by measurements of the very greatest precision. Although the resistance is slightly more susceptible to stray magnetic fields than a well-designed current transformer for the same current, yet the design is such that its characteristics are not appreciably affected by any stray field to which it would be subjected in normal use.†

(2) DESIGN OF $0 \cdot 001$-OHM FOUR-TERMINAL RESISTANCE STANDARD FOR 2 000 AMPERES.

The design may be divided into three parts (see Fig. 1): (*a*) The design of the resistance proper. (*b*) The design of the connections from the resistance to the current terminals. (*c*) The selection of the voltage points and the design of the connections from the voltage points to the voltage terminals.

(*a*) *The Resistance.*

Constantan (copper 66 per cent, nickel 34 per cent) was adopted for the resistance material in preference to manganin on account of its freedom from corrosion troubles, and the ease with which it can be soldered. These advantages were considered to outweigh the disadvantage of a high thermal e.m.f. to copper, which might introduce difficulties in direct-current measurements, but not in alternating-current measurements, for which the standard is mainly intended. The temperature coeffi-

* The Papers Committee invite written communications, for consideration with a view to publication, on papers published in the *Journal* without being read at a meeting. Communications, except those from abroad, should reach the Secretary of the Institution not later than one month after publication of the paper to which they relate.

† R. S. J. SPILSBURY and A. H. M. ARNOLD: "Some Accessory Apparatus for Precise Measurements of Alternating Current," *Journal I.E.E.*, 1930, vol. 68, p. 889.

‡ Time-constant = inductance/resistance. Phase angle = time-constant multiplied by 2π times the frequency. At a frequency of 50 cycles per sec. a phase angle of 1 minute corresponds to a time-constant of $0 \cdot 9_3 \times 10^{-6}$.

§ This advantage is of considerable importance when measurements at low power factors are involved.

† It may be observed that a transformer of the inserted-primary type is unavoidably exposed to a strong magnetic field produced by the primary current, which varies according to the disposition of the primary conductor. On the other hand, it is quite easy to avoid exposing the resistance to a strong magnetic field.

cient of electrical resistance of constantan may be either positive or negative at a given temperature, depending on the exact composition and treatment. The resistivity is given approximately by the equation

$$\rho_\theta = \rho_0 + a\theta + b\theta^2$$

where θ = temperature in degrees Centigrade, ρ_θ = resistivity at θ° C., ρ_0 = resistivity at 0° C., and a

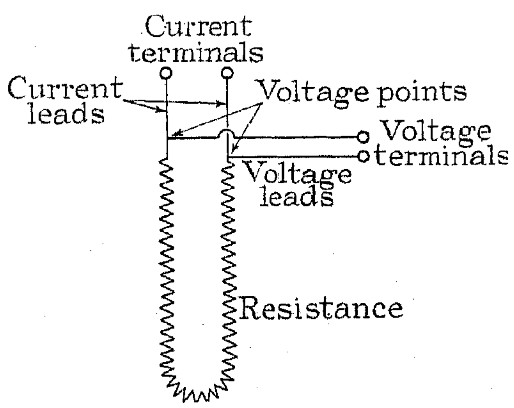

FIG. 1.—Four-terminal resistance standard for alternating currents.

and b are constants (a may be either positive or negative, but b is always negative).

Thus, the temperature coefficient of electrical resistance of constantan always becomes less positive or more negative with rising temperature, and it is not possible to obtain a sample with zero change of resistance over a range of temperature, although the resistance may have the same value at two different temperatures. It is possible, however, by the selection of material of suitable composition to limit the change of resistance to a very small value.

The time-constant of a resistance may be kept to a low value either by constructing it with a small inductance, or by arranging for an e.m.f. to be injected into the voltage leads approximately equal and opposite to the inductance voltage-drop. The former method was adopted for this standard. A low inductance can be obtained only by disposing the resistance element in such a manner as to enclose a very small area. The simplest method of doing this is to use a strip of resistance material bent back on itself, and in this case a resistance element was adopted consisting of a strip of constantan, $1\frac{1}{2}$ in. wide and 0·01 in. thick, bent back on itself at its mid-point. The two halves were separated from each other by two strips of empire tape, each 0·005 in. thick. The time-constant of this element may be calculated from a formula developed by the present author,* and is found to be approximately $0 \cdot 1_4 \times 10^{-6}$. The necessary current-carrying capacity was obtained by connecting a number of these resistance elements in parallel. In order to improve the heat-dissipating qualities of the element the outside faces of the strips were not covered with insulating material. The "lead and return" strips were bound together at intervals of an inch with strong linen thread, and a small piece of keramot placed between the thread and the strip at the mid-point ensured that the strips were maintained close together.

An experiment indicated that a current of 35 amperes through an element would produce a temperature-rise of 50 to 60 deg. C., provided that it was mounted horizontally and with its faces vertical, and provided that its heat dissipation was not reduced by the presence of other elements carrying current. Since the natural movement of heated air is upwards, the heated air from one element displaced horizontally from another element will hardly affect the other element, provided that the horizontal separation is not too small. A horizontal separation of $\frac{3}{4}$ in. between elements was considered sufficient to prevent a serious increase of heating due to the proximity of neighbouring elements. When, however, one element is mounted directly above another, the heated air from the lower element rises to the upper element, so that the effective ambient temperature of the upper element is higher than that of the lower element. This can be avoided only by mounting all the elements in the same horizontal plane. Such a design would result in a resistance occupying a very large floor area and having very little height. A compromise is necessary, and in this case it was decided to mount six elements in a vertical plane. To allow for the heating effect of the lower elements on the upper elements, the

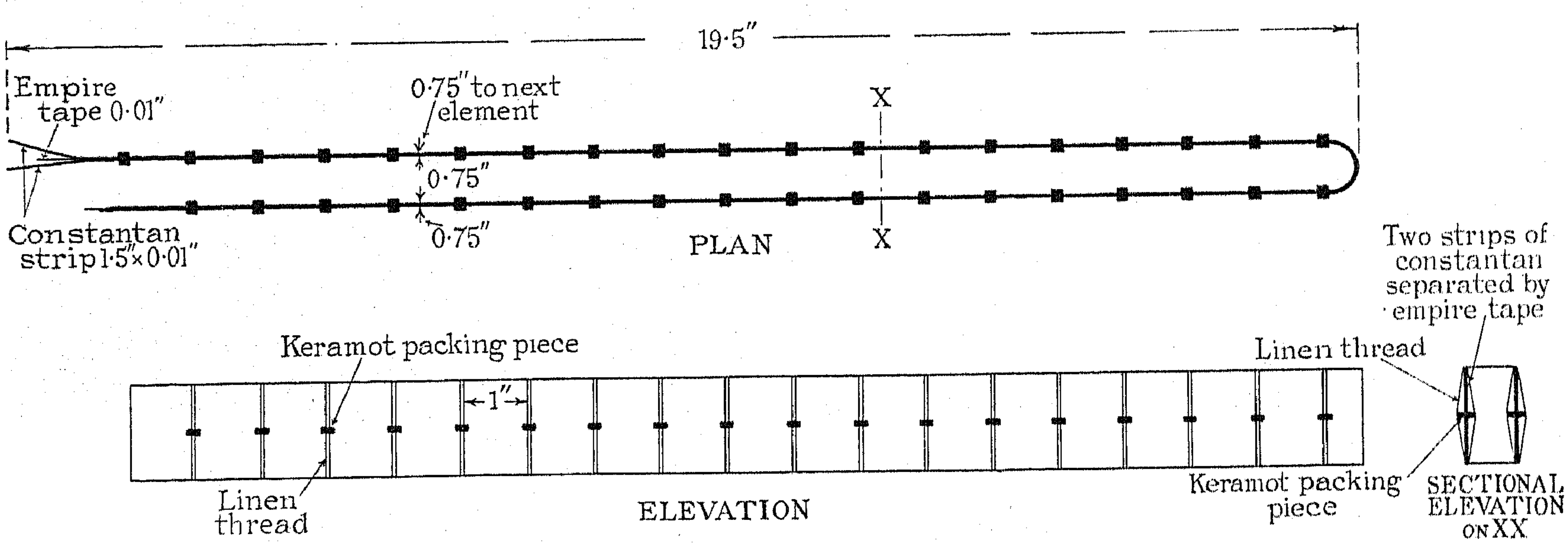

FIG. 2.—Construction of resistance element.

* "The Inductance of Linear Conductors of Rectangular Section," *Journal I.E.E.*, 1932, vol. 70, p. 579.

current per element was reduced from 35 amperes to 21 amperes, so that 96 elements were required in order to carry the rated current of 2 000 amperes.

The resistance of each element is 0·096 ohm, requiring approximately 77 in. of strip. The element was bent as shown in Fig. 2, giving an overall length of 19 to 20 in. Each of these elements constitutes a loop of small area. Magnetic fields produced by external currents could therefore induce an e.m.f. in this loop which would affect the inductance. Alternate vertical rows of elements were therefore arranged to carry their currents in opposite directions, so that the average e.m.f. induced in all the elements by a uniform magnetic field would approximate to zero, thus making the whole resistance

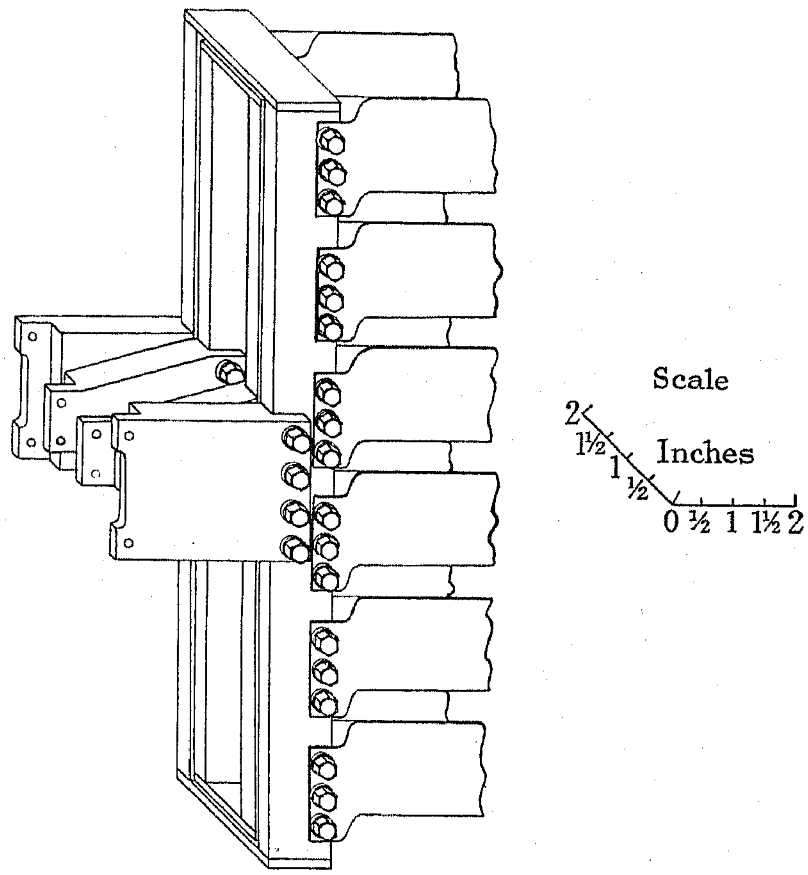

FIG. 3.—Vertical busbars; view showing connection pieces to main busbars, and connections to resistance elements.

astatic. The six elements in each vertical row were clamped at intervals of $3\frac{1}{2}$ in. to wooden posts fixed at top and bottom to the framework of the resistance. The framework was built up with aluminium angles and was mounted on castors to give ease of movement. The sides of the framework were covered with sheet aluminium, but the top and bottom were left open to allow free movement of the heated air. A dust cover was provided for the top, which is removed when the resistance is in use.

(b) The Connections from the Resistance Elements to the Current Terminals.

The ends of the elements in each vertical row were screwed and soldered to vertical brass busbars, of section 1 in. × $\frac{1}{4}$ in. The polarity of alternate pairs of busbars was reversed, thus rendering them approximately astatic. The paralleling of the 16 pairs of vertical busbars was accomplished by screwing and soldering connecting-pieces from the middle of each busbar to horizontal copper busbars running the whole length of the resistance. Fig. 3 shows two pairs of vertical busbars, with connecting pieces to main busbars, and resistance elements. The horizontal main busbars consisted of a central bar, of section 2 in. × 1 in., and upper and lower bars each of section 2 in. × 1 in. The upper and lower bars were connected in parallel, and in this manner approximate astaticism of the main busbars was obtained. Two copper lead-in bars were connected to the main busbars at the centre, and the current terminals were screwed to the lead-in bars near their ends. The lead-in bars were made sufficiently long (12 in.) to ensure the same current distribution in the main busbars for any method of connection of the cables to the lead-in bars.

(c) The Voltage Connections.

The position of the voltage points in standards of low resistance is extremely important. If the voltage points are located near to the current terminals the voltage between them will include not only the voltage drop across the resistance elements but also the voltage drop in the busbars and lead-in bars. It has already been shown that the time-constant of the resistance elements is very small, but, on account of the necessarily large dimensions, the busbars have a comparatively large inductance. Further, owing to eddy-current effects, both the resistance and the inductance of the busbars are dependent on the frequency. In the Appendix to another paper* it was shown that a position could be found for the voltage points which would result in the effective impedance of the four-terminal resistance standard being independent of the resistance or inductance of the busbars. The simple theory given requires considerable elaboration to allow for streams of current flow and other factors involved in actual design, and it is easier to find the correct position of the voltage points by experiment. Fig. 4 shows experimental curves obtained on the completed resistance, which was tested using eight pairs of voltage points. From the figures so obtained, curves were plotted against distance in inches from the centre of the main busbars, which show, as would be expected, that when the voltage points are near the centre of the busbars the time-constant is large and decreases with increasing frequency, while the resistance increases with increasing frequency. The voltage points were finally located at a distance of $10\frac{1}{2}$ in. from the centre of the busbars. It may be seen from Fig. 4 that at this point the change of resistance between a frequency of 50 cycles per sec. and a frequency of 100 cycles per sec. is less than 1 part in 100 000. The change of time-constant in the same frequency range is less than $0\cdot1 \times 10^{-6}$, while the absolute value of the time-constant at a frequency of 50 cycles per sec. is $+\,0\cdot1 \times 10^{-6}$.

The voltage terminals were of the three-terminal back-to-back type described in another paper.† They were located level with the top of the resistance immediately above the voltage points, and connected thereto by leads of copper strip, section $\frac{1}{2}$ in. × $\frac{1}{32}$ in., separated by empire tape 10 mils in thickness. The mid-point terminal was connected to the mid-point of the nearest resistance element. The completed resistance, with sides removed, is shown in Fig. 5.

* R. S. J. SPILSBURY and A. H. M. ARNOLD: *loc. cit.*

† *Loc. cit.*

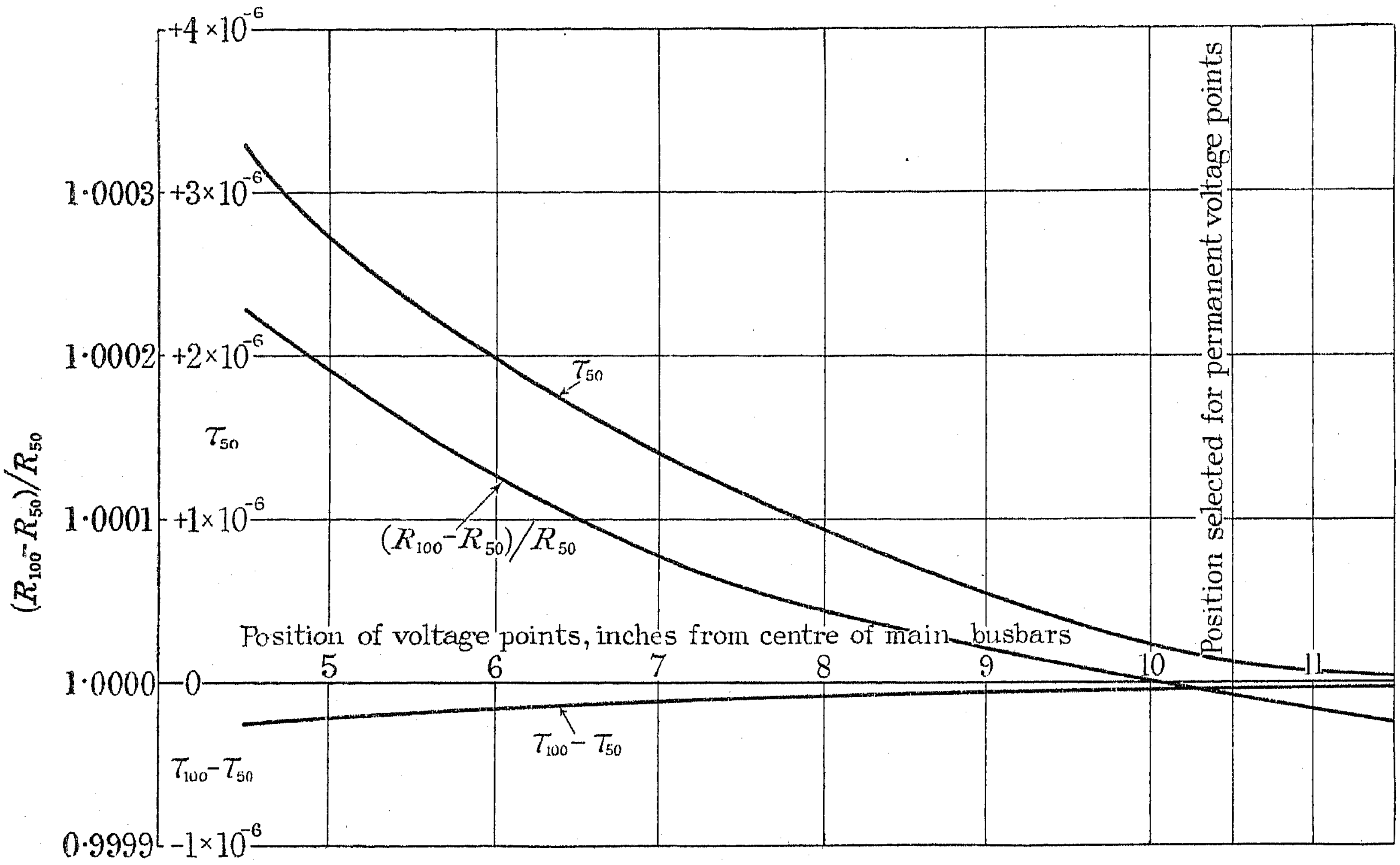

FIG. 4.—Effect of position of voltage points.

R_{100} = resistance of standard at 100 cycles per sec.
R_{50} = resistance of standard at 50 cycles per sec.
τ_{100} = time-constant of standard at 100 cycles per sec.
τ_{50} = time-constant of standard at 50 cycles per sec.
The value $\tau = 1 \times 10^{-6}$ corresponds to a phase angle of 1·1 minute at 50 cycles per sec.

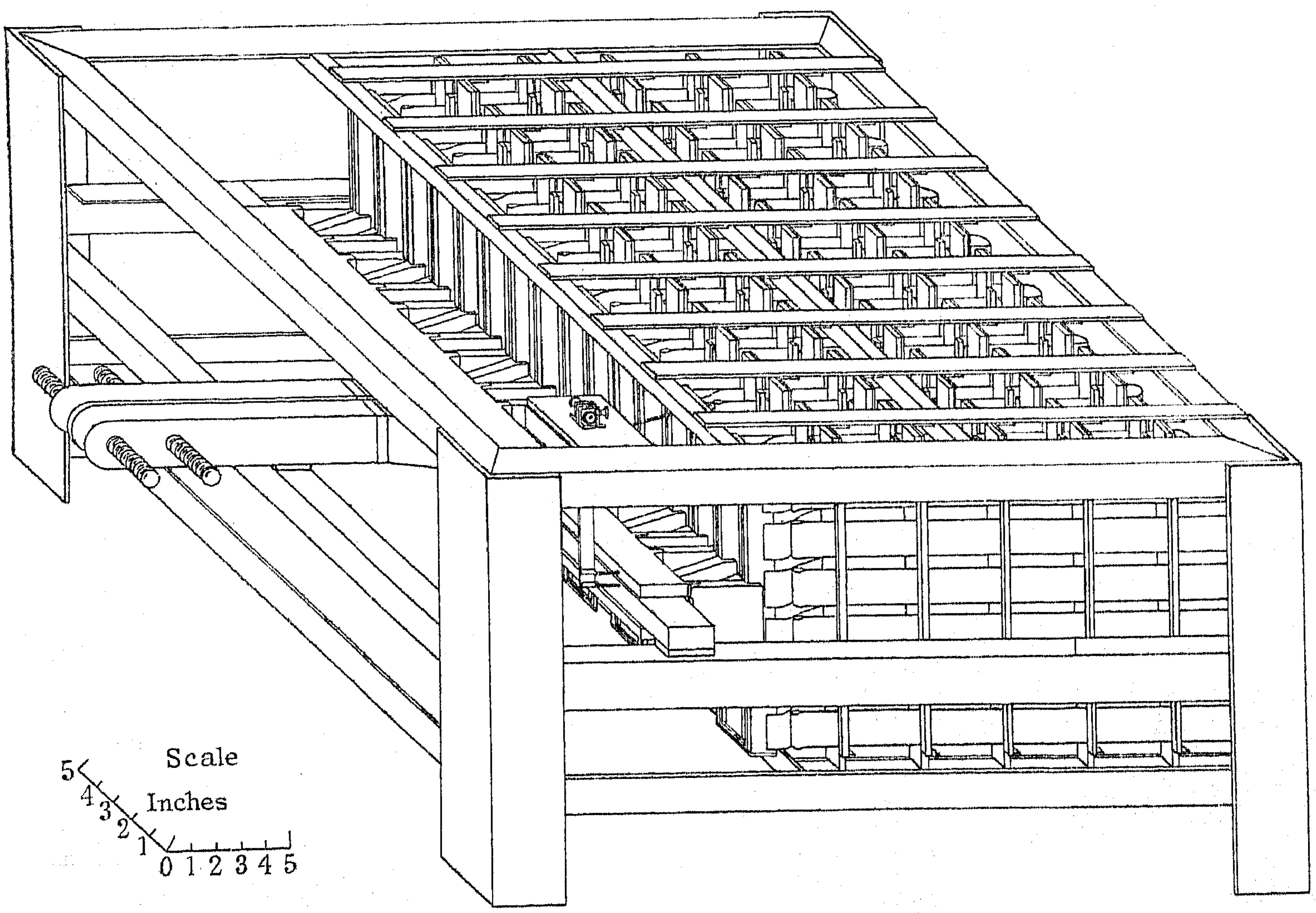

FIG. 5.—2 000-ampere resistance standard.

(3) Characteristics.

(a) Absolute Value of Resistance.

The absolute value of the resistance at the last calibration was 0·0010001 ohm at 20° C. The resistance has remained constant to within a few parts in 100 000 since it was first calibrated a year ago. A careful record is being kept of secular changes.

(b) Variation of Resistance with Air Temperature.

The resistance increases with increasing air temperature at the rate of 8 parts in a million per degree Centigrade in the temperature range 15° C. to 30° C.

(c) Variation of Resistance with Frequency.

The change of resistance between the frequencies of 25 and 100 cycles per sec. does not exceed 1 part in 100 000.

(d) Variation of Resistance with Current.

Fig. 6 shows the variation of resistance with current. In determining this curve, the current was maintained

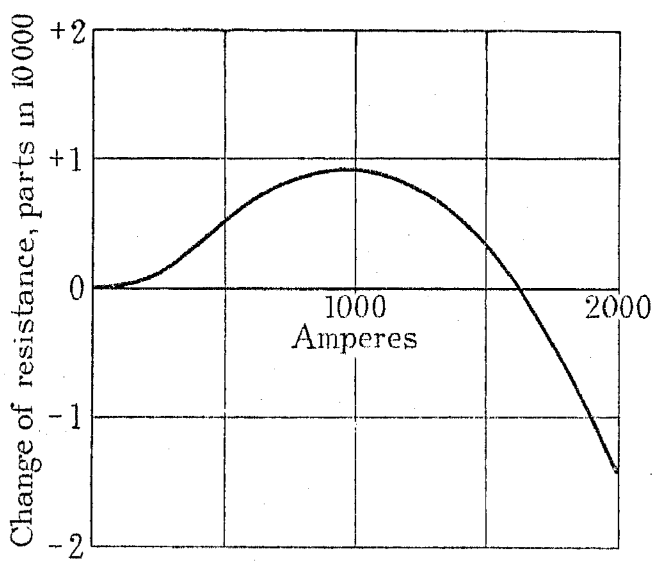

Fig. 6.—Change of resistance with current.

at each value for a sufficiently long period for the resistance to reach a steady value. This period is of the order of 10 minutes. It may be seen that for currents up to 1 900 amperes the resistance departs by less than 1 part in 10 000 from its cold value.

(e) Absolute Value of Time-Constant and its Variation with Frequency.

Fig. 7 shows the absolute value of the time-constant and its variation with frequency for the range of frequency between 25 and 100 cycles per sec.

(f) Variation of Time-Constant with Current.

No variation of time-constant with current was observed.

(g) Variation of Resistance or Time-Constant due to Magnetic Fields.

Since the characteristics of this resistance are to a large extent dependent on the correct position of the voltage points on the main busbars, it is to be expected that a change in current distribution in the main busbars, caused by a magnetic field, would alter these characteristics. A uniform magnetic field cannot induce an e.m.f. in the resistance, since this is constructed astatically, nor can it affect the current distribution in the busbars, but a non-uniform magnetic field can do both. Such a non-uniform field would be produced by the current in the cables connected to the resistance, and by other parts of the circuit. It is possible by disposing a loop of conductor carrying the resistance current round the resistance, with the plane of the loop vertical, to produce a change of resistance of 2 parts in 10 000, and a change of time-constant of $0{\cdot}7 \times 10^{-6}$. Such a severe condition would never occur in practice, and it is more important to consider the changes which are likely to occur. From Fig. 5 it may be seen that the natural direction of the connecting cables is away from the resistance. When only one cable is connected to each lead-in bar, the time-constant and resistance are reproducible to the limits of accuracy of measurement.* When two cables are connected to each lead-in bar, the

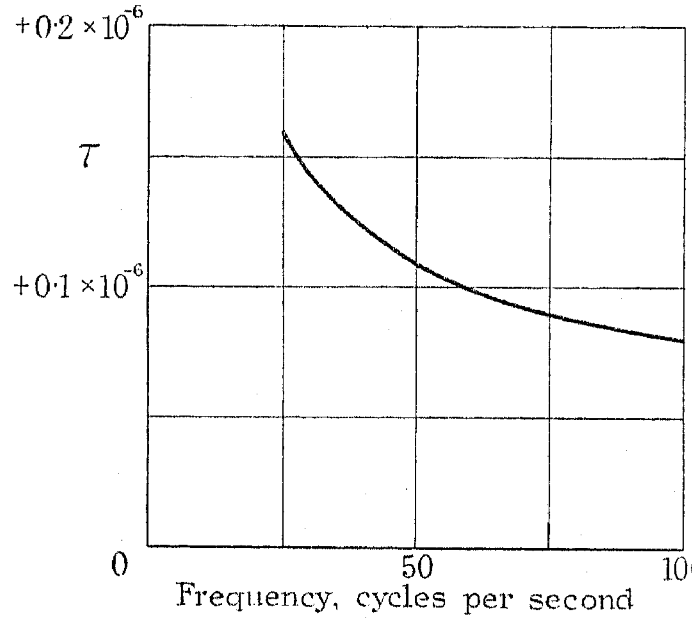

Fig. 7.—Time-constant.

cable connected to the inner terminal may approach the resistance from slightly different directions on each occasion. The angle of approach of each cable was varied through an angle of 45° on each side of the horizontal. The time-constant was found to vary under these conditions by less than $0{\cdot}0_2 \times 10^{-6}$ on each side of the mean value, and the resistance varied by less than 1 part in 100 000.

(h) Thermal E.M.F.

The thermal e.m.f. was measured at full and half rated current, and was found to be less than 1 part in 10 000 of the voltage drop across the resistance. To this accuracy, therefore, the resistance can be used for direct-current measurements, without the necessity of taking reversed readings.

(j) Effect of Resistance Shunts across Voltage Terminals.

In order to secure a definite phase angle and resistance the voltage terminals must be mounted a little distance away from the current-carrying parts, so that the pos-

* These are $\pm\,0{\cdot}01 \times 10^{-6}$ for time-constant and 1 part in 100 000 for resistance.

sibility of an appreciable e.m.f. being induced in the external voltage leads is reduced. In this resistance, the voltage terminals are mounted about 7 in. from the voltage points. For most work, no current is taken from the voltage terminals, and the voltage between the voltage terminals is the same as the voltage between the voltage points. For some measurements it is necessary to connect a resistance across the voltage terminals, which would lower the effective resistance of the standard, partly on account of its shunting effect and partly on account of the voltage drop which would occur in the voltage leads. Tests on this resistance showed that these two effects were almost exactly equal, and a resistance of 100 ohms, for example, connected across the voltage terminals lowered the effective resistance of the standard by 2 parts in 100 000.

The author is greatly indebted to Mr. Gridley, the head of the instrument workshop at the Laboratory, for successfully overcoming the constructional difficulties met with in the course of the development of the resistance.

THE PRACTICAL SOLUTION OF STRAY-CURRENT ELECTROLYSIS.*

By C. M. Longfield, M.Eng.

(*Paper first received 6th November, 1933, and in final form 16th April, 1934.*)

Summary.

The paper summarizes very briefly the methods which the author, in conjunction with an Australian co-operative committee, has developed for investigating and relieving electrolysis conditions.

The paper is divided into several parts. In Part 1, mention is made of the fundamental principles underlying electrolysis phenomena. Part 2 deals with the factors influencing the amount of damage in practical cases. In Part 3, field instruments are discussed and, in particular, reference is made to a double-element photographic recorder. Part 4 refers to the more usual methods of mitigation, and Part 5 discusses very broadly some of the economic aspects of mitigation. The paper concludes with a brief list of references.

Introduction.

The paper describes very briefly the technical methods developed by the author, working in collaboration with a co-operative committee, whereby extensive electrolysis damage arising from the operations of large tramway and railway undertakings has been greatly reduced at trifling cost. For various reasons the identity of the traction systems is withheld, as well as actual figures, such as rail potentials. It is felt that no good purpose would be served by including such information, as the complexity of the problem would make it necessary to support such data with a lengthy description of all those factors which are likely to affect the results.

In the city where the methods herein described were developed, the apparent failure of statutory regulations to limit damage to inconspicuous proportions prompted the formation of co-operative investigating committees. Two committees were formed. The senior committee comprised, in general, the chief engineers of interested utility undertakings, such as electric traction, post office, gas, water, and power-cable-owning authorities, and the chairman of the subordinate or technical sub-committee. The latter committee comprised technical representatives of the utility undertakings, whose duty it was to carry out field research under the guidance of the chairman of that committee.

In the first instance the technical committee investigated cases of reported damage and made recommendations to the senior committee as to the most effective method of relieving each case. A mass of experimental data was soon accumulated, as the result of both field and laboratory investigations, from which important fundamental generalizations could be drawn. Subject to the limitations of brief description, the more important of these generalizations are discussed in this paper. Certain other phases of the subject, such as legal considerations and arbitrary regulations, were referred to in an earlier paper† by the present author.

Part 1. Electrolysis Breakdown.

(a) *Its Nature.*

The breakdown of a metal immersed in an electrolyte, under the influence of an electric current, is now so well understood as not to need any particular emphasis, but certain characteristics which have a direct bearing upon electrolytic corrosion by stray currents are of fundamental importance from an engineering point of view. In the first place, assuming that the density of the current discharged from any given point on a buried conduit‡ can be measured, it does not follow that the life of the conduit can be predicted. Not only does the loss of metal occur in a very irregular manner, but laboratory experiments show that the weight of metal decomposed, though proportional to the quantity of electricity discharged, is not equal to the amount that would be obtained by strict compliance with Faraday's law. This does not mean that the relation discovered by Faraday is not universally true, but rather that secondary reactions and extraneous influences disturb the results. The extent to which the Faraday constant is varied will depend upon the nature of the soil. Research upon this point is meagre, and no satisfactory means of describing the corrosive properties of soil have been evolved. Many workers rely upon pH values, but the author is convinced that the hydrogen-ion concentration by itself is not a sufficient index to this property of the soil. Description of soil by its geological series is certainly not satisfactory.

In the second place, the stray current originating in a traction system is a rapidly fluctuating one, and the incidence of the load and the operation of substations may cause marked changes in the polarity of a conduit with respect to its surroundings from day to day, or even from minute to minute. Some uncertainty arises as to the value of the current to be used in computing the rate of corrosion. If the 24-hour algebraic average is the appropriate one to adopt, then readings over an extended period become necessary. Research shows that the amount of damage resulting from alternating current of commercial frequency is from 0 to 5 per cent of that for equivalent direct current. The frequency of stray currents is altogether too irregular to admit of a definite percentage of the equivalent

* The Papers Committee invite written communications, for consideration with a view to publication, on papers published in the *Journal* without being read at a meeting. Communications (except those from abroad) should reach the Secretary of the Institution not later than one month after publication of the paper to which they relate.

† See Reference (1).

‡ The term "conduit" will be used throughout to denote a buried pipe or cable, as the phrase "underground metallic structure" becomes tiresome by repetition.

unvarying current being assumed, however, as there are short-period and long-period effects both of which are, for most practical purposes, outside the control of the traction authority. In studying this question, it is therefore better to assume that current discharge will cause damage, and that where reversals of flow occur (except where they predominate) it is better to neglect their protective effect.

(*b*) *Chemical Tests for Electrolysis.*

The nature of the decomposition products, the author believes, is not of very great importance. In the past, the end products have been taken as a means of distinguishing stray-current corrosion from auto-corrosion, but, except for the fact that electrolysis corrosion may take place at a speed considerably in excess of that of auto-corrosion, there seems little support for the contention that lead peroxide, for instance, is invariably associated with the former in the case of lead-covered cables. It should be obvious that the end products are a result of the union of the ionized metal and those salts which it encounters immediately it commences its life history as an ion. The environment of the damaged metal is therefore the deciding factor, and not the current which brought about the decomposition, though the speed with which the action proceeds will affect the result.

In Germany, there has been a tendency to accept a concentration of chlorides on the metal surface in considerable excess of that found in the surrounding soil, as proof of stray-current corrosion. While it is logical to accept this—especially in the case of lead-covered cables—it is difficult to see how it can be applied in practice, especially where earthenware or concrete ducts enclose the cables.

(*c*) *Electrical Tests for Electrolysis.*

There are two considerations to be borne in mind when testing by electrical means for stray-current electrolysis. Firstly, the electrical state of the conduit with respect to its surroundings must be determined; that is, is it discharging or collecting current? Secondly, the time/current-discharge curve must be correlated with some source or sources.

Different investigators have put forward various means for determining the electrical condition of a buried conduit. Since current discharge is not uniformly distributed along the surface of a conduit, the most satisfactory means, theoretically at any rate, of measuring the current density of discharge is to measure the density of the discharged current in the earth from point to point around the conduit and along its length. The general objection to this method is that excavation is necessary in most of the cases so far developed. A further objection lies in the method of measuring the current in the earth. Obviously some form of electrode is necessary in order to make contact with the soil. Even though a non-polarizing electrode be used, small differences of potential may be set up owing to differences in the soil structure even over very small distances. In such an event, the apparent discharge of current may in reality be a pick-up of current. It may even be possible to find a conduit apparently collecting current from one side and discharging it on another. Except under very special circumstances indeed, the author believes such a state of affairs to be highly improbable.

As an alternative to the above, it is possible to take simultaneous measurements of current in the conduit at two points some distance apart and deduct the one from the other. If the difference be plotted on a time basis and compared with, say, a potential-difference reading between an adjacent tram rail and earth, it is possible to determine the correlation between the electrical condition of the conduit and that of the rail system. The great practical disadvantage in doing this lies in the difficulty of calibrating the current readings sufficiently accurately to be sure that current is actually being lost. If reliance could be placed upon such current readings, a differentially-wound recorder could be devised for giving directly, when properly calibrated, the current lost or gained over the section under consideration.

All of the above methods depend upon the measurement of current or current density more or less directly. An indirect and qualitative method often adopted is that whereby the potential difference between the conduit and electrified rails (or adjacent buried structure), or between the conduit and an exploring electrode in contact with the adjacent soil, is measured. Except in relatively simple cases, it cannot be taken for granted that, because a metal conduit is found to be positive to an electrified track, it is losing current to it; nor is the magnitude of the current discharge readily capable of determination from the value of the potential difference so found, since the electrical resistances of the elements comprising the circuit are generally unknown.

In order to decide whether a conduit is discharging to a nearby rail (or other conduit) it is necessary to correlate the fluctuation of potential difference between conduit and earth and between rail and earth. That is to say, it can be assumed (other things being equal) that the conduit and the rails are exchanging current if the one becomes more positive while the other becomes more negative to the electrolyte. It is, however, necessary to eliminate the electrode and polarization potentials of the separate metallic elements of the circuit before it is possible to determine whether the conduit is actually discharging or collecting current. This may be done in one of the following ways.

(i) A record of the potential difference between conduit and local reference electrode may be taken over a sufficiently long period to include the no-load or shut-down period of the adjacent traction system. The absolute zero of reference is taken as that part of the record obtained during traction shut-down, as in Fig. 1.

(ii) An approximation may be made by taking simultaneous records of potential difference between conduit and electrode and between rail and electrode as in Fig. 2, and plotting corresponding values; when a graph such as that shown in Fig. 3 is obtained. It is preferable, of course, to use non-polarizing electrodes.

Provided the electrode potentials of the elements of the circuit are small compared with the potential difference between rail and earth, the distance OO″ (Fig. 3) can be assumed to be the resultant of all the electrode effects

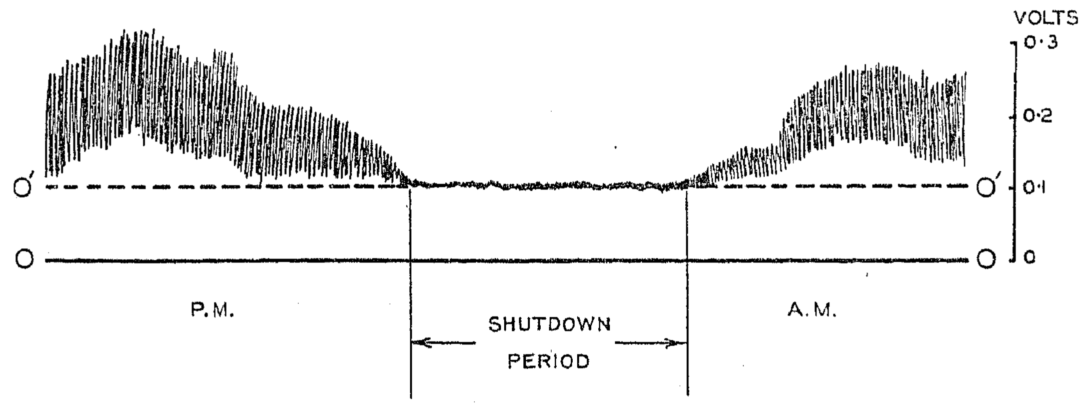

FIG. 1.—Typical record of potential difference between conduit and local reference electrode.
OO is instrument zero.
O′O′ is datum from which potential difference between conduit and reference electrode is measured.

present, and it also includes the polarization potential of the conduit. If tan ϕ is positive in the first quadrant, and the algebraic average potential difference between conduit and electrode lies above O″, it can be assumed

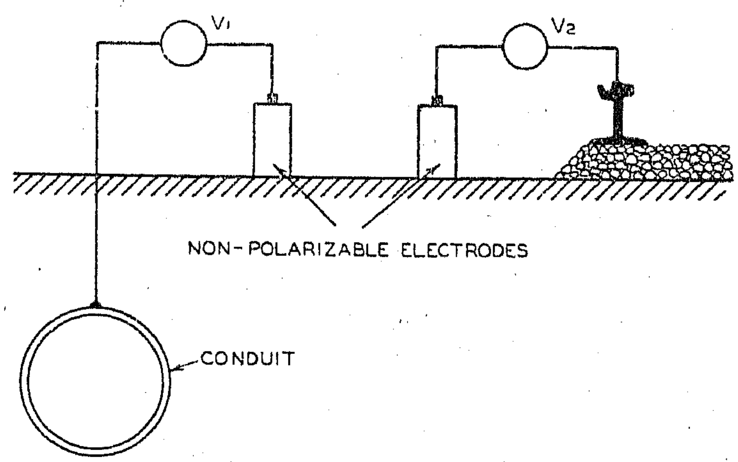

FIG. 2.—Method of correlating rail and conduit conditions.

that discharge is taking place to the local rails. If, however, both of these values are negative, then the conduit is picking up current from the rails.

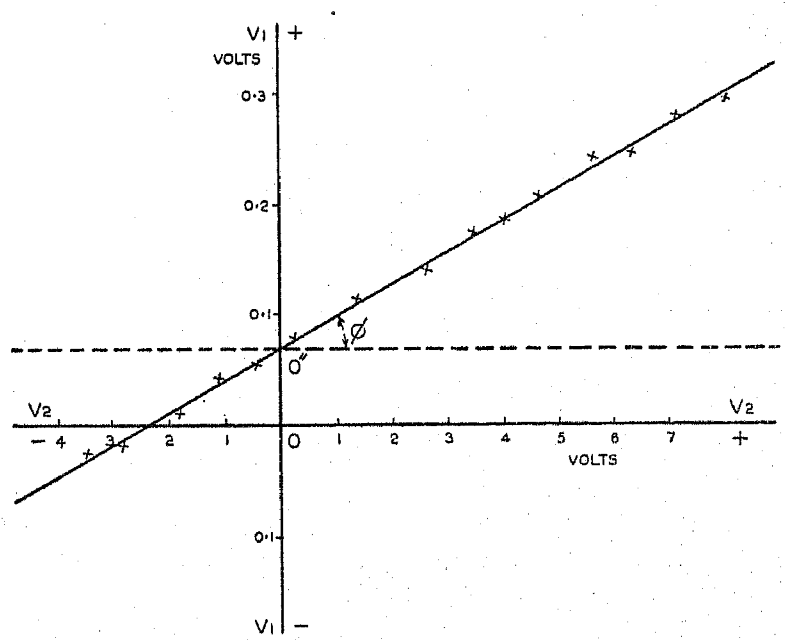

FIG. 3.—Correlation of potential difference between conduit and electrode (V_1) and potential difference between rail and electrode (V_2). Simultaneous readings.

In special cases, it is found that the current in the conduit and the potential difference between the conduit and an adjacent buried electrode oscillate in phase and, when plotted one against the other, give a high degree of correlation. In such a case, the intercept on the potential axis, i.e. the potential for zero current-flow, is assumed to be the reference datum (corresponding to O″ in Fig. 3). If θ be the angular displacement from the x, or current, axis, then for tan θ positive the current in the direction indicated is being discharged. The greater the magnitude of tan θ, the greater the discharge. If tan θ be plotted along a conduit it will generally be found to increase gradually until the point of maximum discharge is reached, when it tends to infinity. Any marked irregularity in the value of tan θ along the route

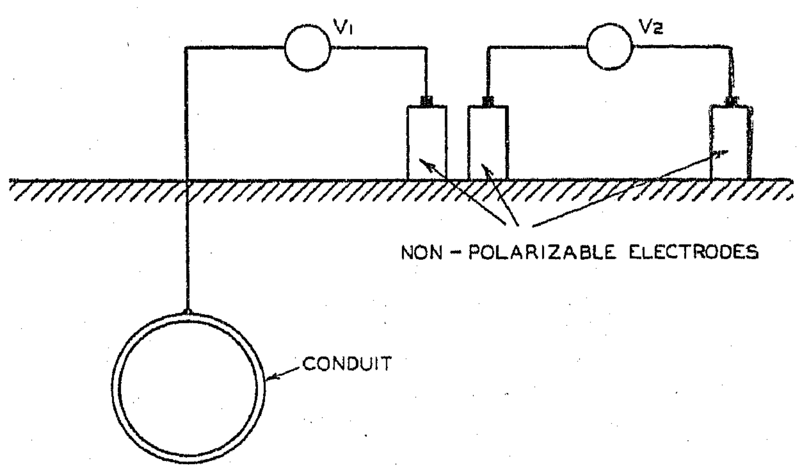

FIG. 4.—Method of measuring polarization potential.

of the conduit indicates a sudden change in the conduit conductivity, e.g. a high-resistance joint, and this method, where applicable, is especially useful in locating high-resistance joints in pipe-lines.*

(iii) An alternative method for determining whether a buried conduit is discharging is that in which the polarization potential of the conduit is measured. As polarization arises from concentration, as well as gaseous, effects, which may be described as long-period and short-period effects, it is necessary to note that it is only the relatively longer-period effects which can be measured in practice unless very special arrangements are made. Fig. 4 indicates the method with which the author has experimented. It entails the simultaneous recording of the potential difference between two non-polarizing electrodes placed in the earth on a line at right angles to the run of the conduit, and the potential difference between the conduit and a third (reference) electrode.

* For a fuller discussion of this aspect, see Reference (1).

Except where the conduit is in close proximity to an electrified track or other buried metallic structure, a very high degree of correlation will be found between these records. If polarization were absent, the readings would bear a constant relation to each other. Want of such an agreement, as the current discharge varies in magnitude, is an index of polarization. The sign of the polarization potential determines whether the conduit is discharging or collecting current.

All of the above methods render it necessary to make contact with the metal under observation. Where this is inconvenient, a prospecting method similar to that suggested by the Schlumbergers* may be used as an approximation.

Part 2. Characteristics of Stray Currents.

(a) *Their Origin.*

Earth currents may arise from one of the following sources:—

Either alternating-current or direct-current.—(i) Uninsulated returns of electric traction systems. (ii) Faulty electric installations, feeders, or equipment, or where multiple-earthed neutral systems are used. (iii) Signal circuits.

Direct-current only.—(i) Telegraph or telephone exchange currents, e.g. private board exchange currents. (ii) Galvanic currents arising from the connection of dissimilar metals embedded in the earth, or from concentration-cell effects on a single metal. (iii) Natural earth currents.

For the purpose of this discussion, alternating-current effects will be disregarded. Direct currents arising from any of the above sources, with the possible exception of the last-mentioned item, are capable of causing corrosion to a degree depending upon the magnitude of the current, the configuration of the conductors, and the soil conditions.

In the next section, special consideration will be given to the effects of stray currents arising from electric traction systems. It is perhaps unnecessary to discuss the effects of leakage from faulty installations, etc., since these are, from an electrolysis point of view, sufficiently rare, and of such a short duration, as to be relatively unimportant. Multiple-earthed neutrals, at the present time, deserve no more than mere mention.

Of the remaining items mentioned above, exchange currents and galvanic effects are the most important. The use of the bare lead-sheaths of telephone cables as returns for exchange currents subjects these sheaths to damage by electrolysis, since the potential gradient along the cable sheath will result in the diversion of a certain amount of current to earth. Damage from such a cause is not unknown, though the presence of electrified tracks renders experimental proof difficult, if not impossible.

Dissimilar metals in contact in the earth can, under favourable conditions, cause currents of such magnitude to circulate between them that one or other of the metals will be rapidly destroyed. The author has observed, in a bad stray-current electrolysis area, effects of this nature considerably greater in intensity than the effects set up by the stray currents. One remedy involves the insertion of an insulating joint at the junction of the metals, but as this presents a point of mechanical weakness it is perhaps better to insulate the attacked metal from the electrolyte by a waterproof covering.

* See Reference (2).

Doubt has been expressed as to whether what are known as "long line currents," found on pipes which traverse soils of varying composition, do actually cause corrosion. There is very little published information upon this subject.

(b) *Factors Influencing the Amount of Stray Current resulting from the Operation of Electric Traction Systems.*

Parliamentary Acts, concerning the establishment of electric traction systems, allow the use of uninsulated rail returns, and, since the phenomenon of stray-current electrolysis has been known for a very long time (it was the subject of investigation by a Parliamentary Committee under Viscount Cross in 1893), it must be supposed that the legislature is cognisant of the presence of stray currents originating in this manner, and of the danger which they constitute to underground metallic structures. The old Board of Trade Rules also permit the use of uninsulated returns, but they stipulate that the resulting stray currents shall not cause damage to buried cables, etc. As electrical drainage is prohibited by these rules, it would appear that the traction authority has been deprived of an economical, and at least partially effective, remedial measure. The present discussion will avoid further reference to the legal side of this problem.

The impact which electrolysis makes upon the engineer is a technical one. It presents itself either as a question of designing a traction system to reduce to a minimum the electrolysis hazard, or as a question of mitigating bad conditions which are found to exist. It is necessary, therefore, to get a quantitative idea of the factors influencing the hazard to underground plant.

Various writers have evolved mathematical treatments which are, at best, only very rough approximations to actual conditions. Those developed by the Bureau of Standards* represent the effect of the earth and the road bed by a uniform leakage resistance interposed between the rails and an infinitely conducting plane, while the work of Michalke† assumes that conductors are in contact with an infinite and homogeneous medium.

While neither of these assumptions represents the actual case, they lead to important generalizations which are helpful in studying the problem.

(i) *Track leakage-resistance and rail potential.*—In the following discussion, the effect of the resistance of the general mass of earth under the road bed will be combined with that of the leakage resistance of the road-bed proper in the generic phrase "effective track leakage-resistance." For the purposes of comparative analysis a uniformly distributed loading of the track will be assumed.

The magnitude of the current leaking from the rails may be taken as a criterion of the hazard to underground plant, though the disposition of the latter will have a

* See Reference (3). † *Ibid.*, (4).

direct bearing upon the actual damage resulting in any given case. Figs. 5 and 6 show in a striking manner the influence of length of track, and of track leakage-resistance, upon the amount of current escaping to earth. Here r ohms is the track resistance per 1 000 ft., $i_{lmax.}$ the maximum leakage current, and i_0 the train load per 1 000 ft. of track (in amperes).

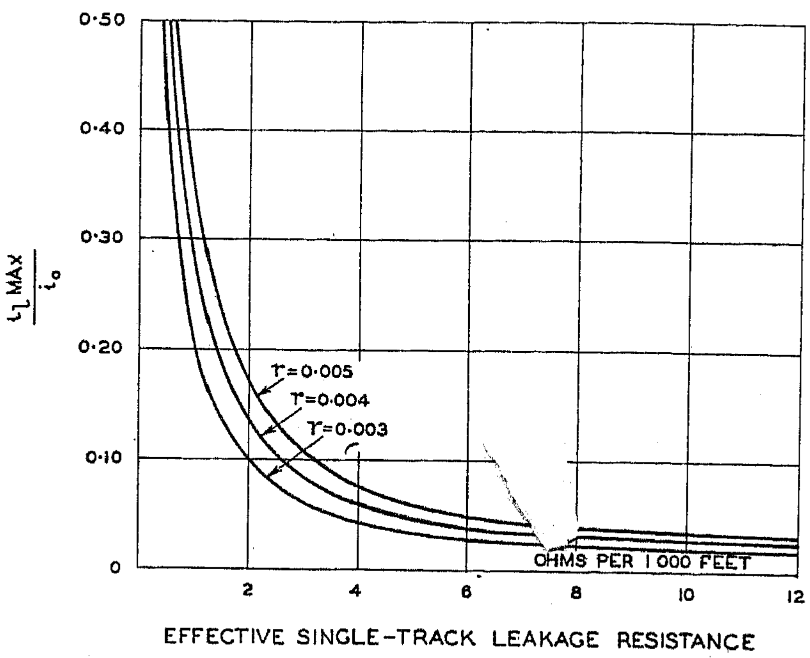

FIG. 5.—Leakage current from track 10 000 ft. in length.

The measurement of track leakage-resistance is relatively difficult to carry out in practice, and attempts to classify different types of tracks by description are apt to be misleading. In general, it may be said that the leakage resistance of tracks laid flush with the road surface, as is done with tramway or street-car systems,

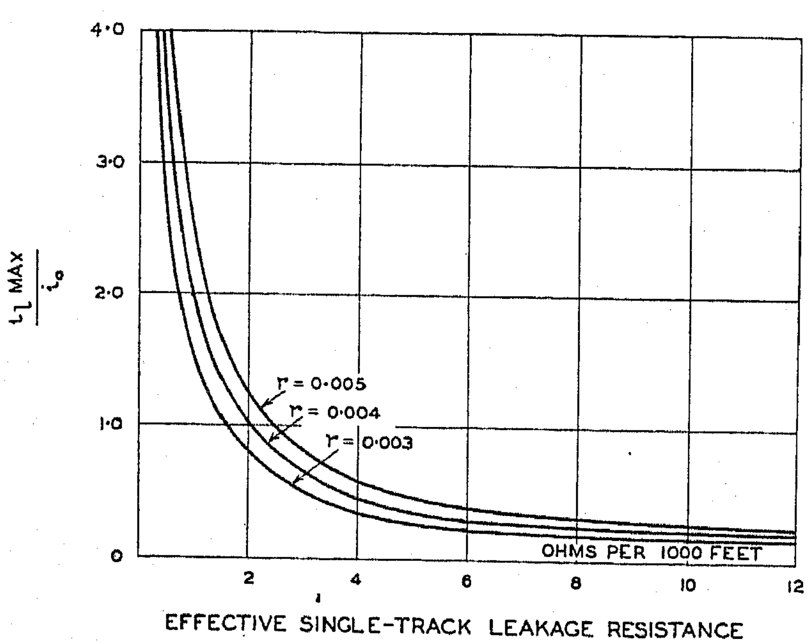

FIG. 6.—Leakage current from track 20 000 ft. in length.

is well under 5 ohms per 1 000 ft. Indeed, tests have given figures as low as 0·25 ohm per 1 000 ft. In this respect a concrete road surface is no better, and may even be worse, than other types of construction. Rails laid upon open ballast usually give a figure of over 5 ohms per 1 000 ft., but they are much more susceptible to the influence of the weather; in wet weather the leakage resistance will fall very considerably. The author has observed figures ranging from 5 to 50 ohms for a particular section of track under different weather conditions. Level crossings occurring in ballasted trackwork reduce the leakage resistance greatly, and it usually happens that major underground conduits cross the track at such points, so that any benefit which might be derived from the open-ballast construction is practically lost through the higher leakage occurring at such crossings, as well as through the intimate relationship of the affected structures.

The track conditions are frequently specified with regard to the maximum potential gradient, or the maximum overall potential-drop. The effect of varying both length and leakage resistance can be appreciated from Table 1.

It will be concluded that the length of track has, other things being equal, a very marked influence upon the amount of current leakage, and therefore upon the electrolysis hazard. It will also be obvious that the track should be insulated, as far as practical considera-

TABLE 1.*

Approximate Values of Maximum Leakage Current and Overall Voltage-Drop, assuming a Potential Gradient of 2 Volts per Mile in the Rail at the Substation.

$\frac{1}{g}$	Maximum leakage current (amps.)			Overall voltage-drop (in volts) for		
	$l = 10$	$l = 15$	$l = 20$	$l = 10$	$l = 15$	$l = 20$
0·5	4·4	8·9	13·9	1·7	2·4	2·9
1·0	2·5	5·4	9·1	1·8	2·6	3·2
5·0	0·4	1·0	1·9	1·9	2·8	3·7

* In this Table, l = length of track, in 1 000 ft.; rail resistance = 0·005 ohm per 1 000 ft. of track; and g = track leakage conductance, in mhos per 1 000 ft.

tions will allow, from the general mass of earth. The connection of the negative busbar at the generator or substation to earth plates, as prescribed in the old British Board of Trade Regulations, constitutes a serious menace to underground conduits on account of the increased leakage of current which it encourages, and it serves no good purpose whatever. The author knows of a case where such a connection gave rise to very serious damage to telephone cables over a wide area. Its removal was quickly followed by a very marked improvement in electrolysis conditions.

The limitation of rail potential to a specified amount, such as the 7 volts mentioned in the Ministry of Transport regulations, does not define the amount of current leakage. The manner in which current leakage may vary is indicated in Fig. 7. That such variations do exist is within the author's own experience.

There remains now the potential difference between cable and rail (or, what is practically the same thing, the potential difference between rail and earth) as a criterion of electrolysis conditions. For a given loading and rail section, the rail-to-earth potential will be determined entirely by the track leakage-resistance being lower the smaller the resistance of the road bed. For an isolated length of track fed from one end only, and

not earthed at the generator end, theory shows that for a potential difference of 1 volt (rail positive) between rail and earth at the remote end there should exist a potential difference between rail and earth of 2 volts (rail negative) at the generator end. Earthing of the rail or of the negative busbar will have the effect of reducing the rail-to-earth potential, but at the same time the leakage current will be materially increased, to the detriment of buried conduits. Another condition tending towards the same result is observed when the generator (or substation) is at the junction of several lines; in this case car movements upon one section of track give rise to leakage currents which return to other sections as well as to that part of the section considered which lies near the generator. It therefore generally happens in practice that the potential difference between rail and earth at termini is several times greater in magnitude than that at the generator, but opposite in sign.

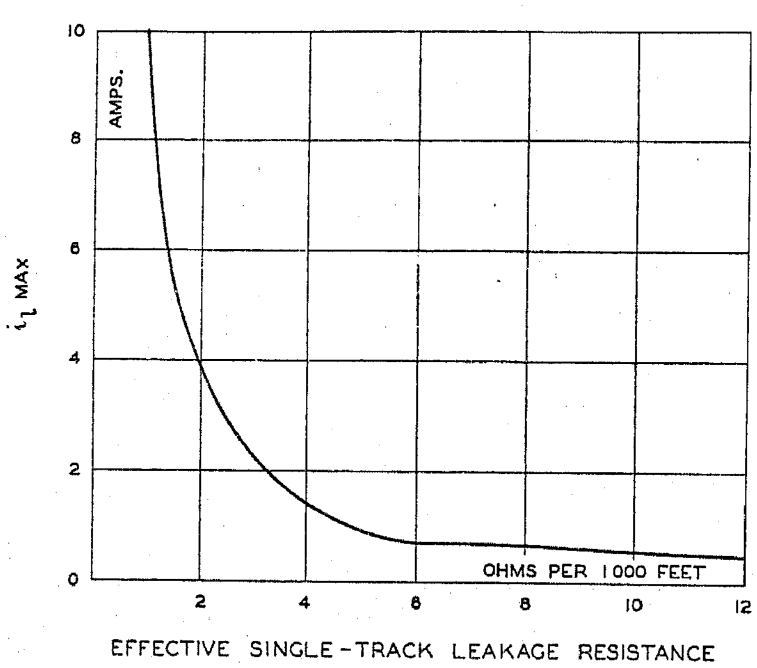

FIG. 7.—Leakage from a rail section 10 000 ft. in length with an overall potential drop of 7 volts.

(ii) *Substation operations and load characteristics.*—The problems confronting engineers some thirty or forty years ago were vastly different from those with which the electrolysis investigator has to contend to-day. Not only were the installations then very much less extensive, but also parallel-operated substations were unknown. The operation of substations in parallel has completely changed the whole aspect of the problem.

When two substations are coupled in parallel on the d.c. side it cannot be assumed that the division of the load occurs at a point midway between them. An unsymmetrical division of the load may arise from unsymmetrical grouping of cars or from a want of voltage balance between substations. Such dissymmetry increases the effective length of the more heavily loaded section of the track, and, as the leakage varies approximately as the square of the track length, it will be seen that the electrolysis hazard may be very greatly increased by this means. Anyone familiar with the characteristics of a traction load will appreciate the great difficulty in maintaining a balanced distribution of the load between substations. Lack of voltage balance is brought about not only by bad operation; it may also arise from the want of identity of convertor characteristics, or from the characteristics of the system as a whole, e.g. from a.c. feeder drop. Such a state of affairs is inherent in a transmission system in which, as shown in Fig. 8, one feeder supplies a number of substations. By paying insufficient attention to a.c. feeder design, the precautions taken to ensure special characteristics for convertors may be completely nullified.

As the load changes during the day, cyclic fluctuations occur in the distribution of the load between the substations. In particular, the conditions at the most remote substation will be very unstable. Such a state of affairs may be serious where highly-conducting steel pipes parallel the route of the track since, at times of heavy load, current will flow towards the inner substations. This current may reverse at times of light load, and protection by drainage bonding is rendered difficult. Moreover, the effective length of the "exposure" is so great under these conditions that relatively small potential gradients may cause serious damage.

Localized lead-covered cable networks may suffer serious damage owing to the discharge of current from cable ends under the unstable conditions noted above. The protection of such cables by electrical drainage is generally impracticable.

Before leaving this aspect of the problem, it is necessary to mention the effect of car headway upon the rail conditions. It generally happens that an infrequent

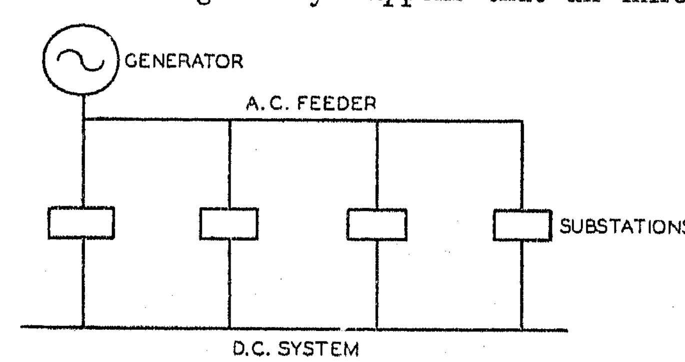

FIG. 8.—Network supplying four convertor substations.

service is maintained on the outer sections of an electrified railway system, and at certain times of the day there may be no train movements between two outlying substations. The track included between these substations will therefore act as a negative feeder to the rest of the system, and buried conduits along its route will discharge current even at those points (e.g. the mid-point) where, under more usual circumstances, the rails would be positive to earth. The rail potential-gradients, in this case, may be quite small.

Part 3. Field Instruments.

Naturally, the type of instrument suitable for electrolysis surveys depends upon the nature of the readings to be obtained. In general, the following field data will be required. (1) Potential difference between conduit and rail. (2) Potential difference between conduit and reference electrode, and between rail and reference electrode. (3) Current in conduit, e.g. in pipe, cable sheath, etc. (4) Current in drainage bond. (5) Current density of discharge from conduits.

Owing to the rapidly fluctuating nature of the traction current, observations based upon indicating instruments are not entirely satisfactory. Where they have to be relied upon, readings taken at 15-sec. intervals over a period of about 20 minutes should be obtained. With this method, it is not always possible to ensure synchronization of readings, even if observers are close together.

From every point of view, therefore, recorders are superior, but for both indicating instruments and recorders a high instrument resistance, as well as a high degree of sensitivity, is required for the readings mentioned above; except for items (1) and (4), which may, if necessary, be measured on the usual commercial instruments.

The author has used a double-element recorder for field investigations, and it has been possible by this means to correlate effects under observation. The recorder consists of two Tinsley stretched-suspension centre-zero galvanometers, giving a deflection of about 1 cm per micro-amp. with a coil resistance of 300 ohms. Suitable shunt and series calibrating resistance units are incorporated in the case, while the light beams are brought to a focus on a Cambridge drum recorder by means of a semi-cylindrical lens. An inclined mirror is rotatably mounted in front of the lens to project the light beams on to a ground-glass screen during adjustment. Bromide paper receives the record at a speed of 40 cm per hour for tests of short duration, while an auxiliary attachment feeds on chart paper at the rate of 4 cm per hour for 2-day records.

The non-polarizing electrodes used in field surveys are best made of the same kind of metal as the conduit under investigation, in order to reduce to very small limits the electrode potential, which appears as an error of unknown amount in measurements of potential difference between conduit and earth.

Part 4. Methods of Mitigation.

On the assumption that uninsulated negative returns are used, the various practical measures which may be applied are in the nature of palliatives, whose effectiveness depends upon technical and economic considerations. In the following section, brief mention will be made of the relative costs of different methods of reducing the electrolysis hazard. The more obvious technical measures will now be discussed.

(a) *Drainage Bonding.*

Perhaps the author will be criticized for referring to electrical drainage first. While it would not appear, at first sight, to offer a satisfactory solution, its very cheapness prompts its consideration as a means of relieving cases of known damage, and, in any case, a certain amount of drainage is a necessary part of any scheme of mitigation.

The objective in electrical drainage is the elimination of those positive areas on a buried conduit from which current is discharging to earth. Such danger areas may appear at any point of the conduit system, their location being determined by the stability of the traction system (freedom from voltage unbalance as between adjacent substations), the incidence of the load, the traction lay-out, and the disposition of the buried conduits.

In general, this method of protection is really only applicable to a restricted area around the negative rail taps, where, with a reasonably stable traction system, practically the whole of the damage will occur. It will usually be necessary to supplement this by other means, which will be mentioned later.

In protecting a conduit in this manner, the following precautions must be observed. The conduit must be maintained at all times only just sufficiently negative* to soil to prevent discharge at any point along its length. If this condition is not observed, dangerously high potentials may be set up between the conduit so protected and an adjacent one, to the detriment of the latter. The electrical conductivity of the conduit so treated must not be impaired by high-resistance joints. The possibility of reversals of polarity causing feed-back through the drainage connection must be prevented

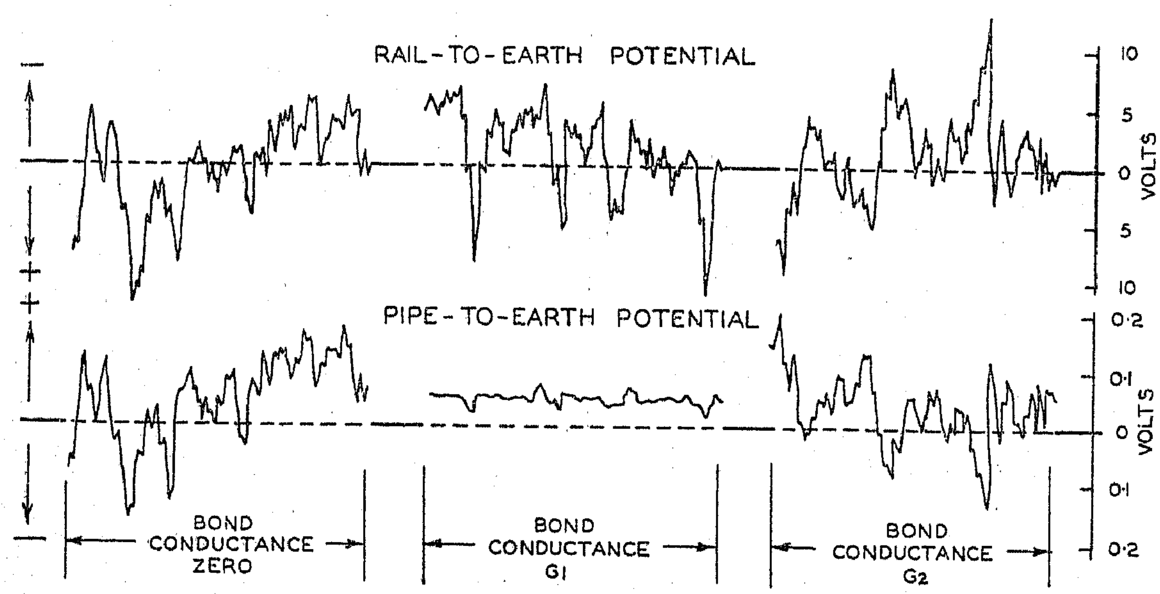

FIG. 9.—Camera records of potential difference between pipe and earth and between rail and earth with bond conductances of zero, G_1, and G_2, mhos. These values correspond to bond settings—undrained, correctly drained (approx.), and over-drained.

* In the case of steel pipes it may be necessary to over-drain them, thus utilizing the stray currents to provide "cathodic" protection against soil corrosion.

by means of a unilateral device.* Where these precautions are observed, highly satisfactory results should be achieved.

In general, the drainage connection should be attached to the conduit system at the point of maximum discharge. The location of this point may be found by electrical tests; but as such tests are frequently qualitative only, resort may be made to statistical records of reported damage.

The point of attachment having been decided upon, it is necessary to adjust the resistance of the drainage connection to satisfy the conditions outlined above. In illustration of the method used by the author, and which is believed to be entirely novel, it will first be assumed that a high degree of correlation is found between the potential differences between conduit and earth and local rail and earth. At least three inde-

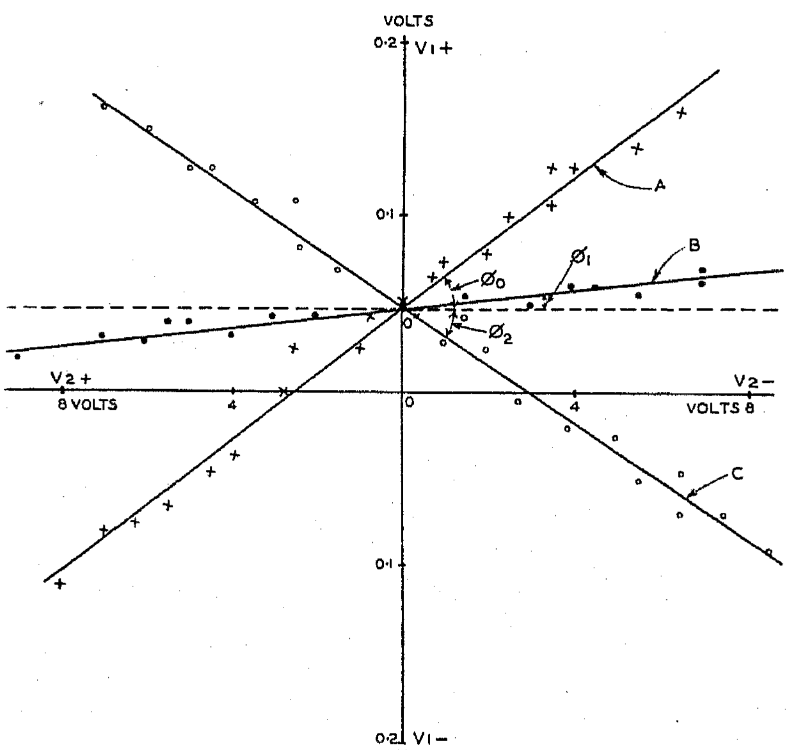

FIG. 10.

Curve A.—Bond conductance = 0.
Curve B.—Bond conductance = G_1 mhos.
Curve C.—Bond conductance = G_2 mhos.

pendent tests are carried out, with as many bond-resistance values. Fig. 9 depicts a small section of chart obtained for this purpose.

From the data of Fig. 9, a correlation chart may be plotted as described for Fig. 3. The result is given in Fig. 10, which shows the results obtained without the rectifying device mentioned above. The inclusion in the bond of a copper-oxide rectifier gives to the graph a slightly parabolic form.*

From Fig. 10, the values of θ_0, θ_1, and θ_2, are obtained, and these are plotted against the corresponding values of bond conductance. In this way, the critical value of bond conductance, which gives zero potential difference between conduit and earth for all values of rail potential, is obtained. It cannot be assumed that a drainage bond designed in this way will maintain the conduit at zero potential with respect to the surrounding soil for all time. Changes in the weather will affect the

* See Reference (5).

road-bed resistance (especially open ballast), so that the bond should be designed for the wet weather conditions. This will lead to over-drainage in dry weather, but the leakage currents will then be less.

The above analysis presupposes a high degree of correlation between the rail and conduit conditions. Where only poor correlation is found, as sometimes happens when the conduit is drained to a negative feeder or busbar, it is necessary to obtain a chart similar to that shown in Fig. 1 and, in any case, it is as well to check the bond setting from such a record.

In special cases, where insufficient voltage exists to ensure adequate protection by draining, a " boosted " drain has been used.* In this case, a copper-oxide rectifier unit, taking supply through a transformer from a local a.c. lighting circuit, is connected in series with the drainage bond and the rail to ensure a flow of current sufficiently great to lower the conduit potential the requisite amount.

(*b*) *Reduction of Leakage from Rail.*

Mention has already been made of the factors influencing the amount of current leaking from uninsulated returns. In particular, it has been shown (see Figs. 5, 6, and 7) that the leakage resistance of the road bed is a very potent factor in influencing electrolysis corrosion. For leakage-resistance values under 5 ohms per 1 000 ft. of single track, the leakage current becomes a very large proportion of the rail current. Measurements of rail potential will probably fail to detect these unsatisfactory conditions (see Fig. 7). Every endeavour should therefore be made to insulate the rails from the general mass of the earth, and rail conductivity, as affected by rail bond resistance, should be maintained at as high a figure as possible. Other means of limiting leakage, such as by reduction of rail potentials, have been treated fully by other writers.

(*c*) *Waterproofing of Buried Conduits.*

The high degree of immunity from electrolysis attack enjoyed by power cables, which are either armoured or laid solid in bitumen, suggests that similar treatment might be afforded to other conduits. In particular, telephone cables offer a field in which some modification of power-cable practice might be exploited to advantage. It is certainly desirable that the more permanent trunk and junction cables should be so treated. Laterals, however, present a special problem, in that replacement due to expansion of business is frequently necessary. For this reason duct construction is virtually a necessity, so that cables may be withdrawn. Either the ducts must be maintained watertight (a difficult matter in practice), or else a protective covering that will not be too costly and that will not, at the same time, interfere with the withdrawal of the cable, is desirable. It is probable that such a covering will be developed shortly.

Similar protection for water and gas pipes, especially in the larger sizes, is costly. Here the chief problem seems to be avoidance of damage in transit and while laying. At the same time, the effects of electrical endosmose† make the adequate protection of a large pipe surface very difficult. Gill‡ has covered modern practice

* See Reference (5). † *Ibid.*, (6). ‡ *Ibid.*, (7).

in an able article recently; the development of a satisfactory waterproof covering for steel mains is long overdue.

(d) Zinc Plates.

As early as 1922, Bartholomew* described the protection of the Berlin–Hanover trunk telephone cable by zinc earth plates so arranged as to counter the effects due to natural earth currents. The attachment of zinc earth plates is helpful in combating electrolysis due to currents arising from local concentration-cell effects, and for the protection of cable laterals subjected to the conditions of fluctuating stray currents noted in Part 2, Section (*b*) (ii). In this latter case, the electrical effects are generally comparatively small and electrical drainage to the rail is not always convenient at such points. If a zinc plate of suitable gauge and measuring about 2 ft. × 2 ft. is connected by a well-insulated lead to the cable sheath, considerable protective effect, as evidenced by an appreciable lowering of the potential difference between cable and earth for some distance, is obtained, provided the soil is sufficiently highly conducting. The life of such a plate should be at least 5 years, and, as the cost is negligible, such a form of protection is sometimes justifiable. It has the disadvantage of requiring supervision and replacement.

Much the same effect can be obtained by enclosing cable laterals in galvanized-iron piping. In this case it is necessary to connect the lead sheath to the metal pipe. Neither the use of zinc earth plates nor the use of galvanized-iron pipes is as effective as an insulating covering, which will not only prevent the discharge of current but will also prevent the pick-up of current on the numerous laterals of a telephone network, thereby augmenting the amount of current in the main cable runs.

(e) Insulating Joints.

Many engineers have advocated the use of insulating joints for the protection of both pipes and cables. The author is not favourably disposed towards them. In the first place, they make electrical drainage difficult, and in the second they constitute a source of mechanical weakness. They should not be used on large pipes or cables, but may sometimes be used with advantage on small cable laterals.

Part 5. Comparative Costs of Mitigative Measures.

From what has already been said it should be amply clear that the criteria popularly accepted, namely, rail potentials, are not sufficient in themselves to define the amount of damage that may or may not occur. Rail potentials are an incomplete specification, and the enforcement of an arbitrary standard (for that is all regulations can be) may involve the traction authority in an expenditure out of all proportion to the benefits gained.

The factors affecting the amount of damage are track resistance, traction loads and their incidence, voltage regulation, track leakage resistance, soil conductivity, material of which conduits are made, surface leakage resistance of conduits (quality of insulating covering, if any), state of wetness of ducts, and configuration of conduits with respect to the traction system. It will be observed that some of these factors are quite outside the control of the traction authority. In order to reduce the rate of damage in any given case, it is necessary to incur expense either in the reduction of rail potentials, or in providing insulation at some point or points, or in providing electrical drainage. It may be necessary to do a little of each. The actual measures to be adopted can only be arrived at by a thorough investigation of all the points involved. Each case must be taken upon its merits, and sincere co-operation between all the parties interested must be obtained.

Obviously, detailed cost data are out of the question in a paper such as this, but brief mention should be made of the relative amounts involved, in order to illustrate the need for a careful economic study in cases of reported damage. Under Australian conditions, the cost of a drainage bond, including a rectifier, is about £30 for all labour and material. In a case with which the author is familiar, 73 such bonds, installed over a period of 4 years, were mainly instrumental in reducing cable faults in an area of approximately 400 square miles in the manner indicated in Fig. 11. In this area, a street-car system operates 19 substations, while the electrified suburban railway operates 23 substations. Rail voltage-drops conform to recognized practice.

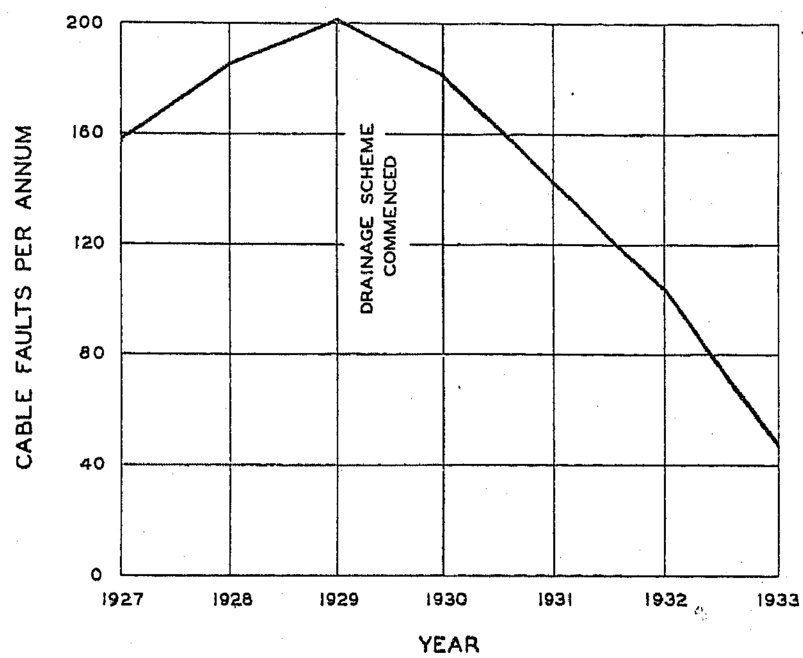

Fig. 11.—Cable faults reported as being due to electrolysis.

Apart from electrical drainage, general improvement of the conditions was effected by balancing, as far as possible, the substation voltages. In addition, a few zinc plates and insulating joints were installed, while two boosted negative feeders were erected.

The high cost of reducing rail voltage-drops can be illustrated by making some simple assumptions. Assume that feeder copper costs 1s. per lb. and energy 1d. per kWh. First consider the limiting case of increasing the rail conductivity by bonding copper cables in parallel with the rails. Estimates will be made for one route mile of double track using 102-lb. per yard rails. The cost of copper alone would be as shown in Fig. 12.

* See Reference (8).

Next consider the more economical method secured by the installation of graded negative feeders whose resistance may be so arranged that a given potential gradient is not exceeded. In this case, energy is lost in heating the negative feeders, so that it is necessary

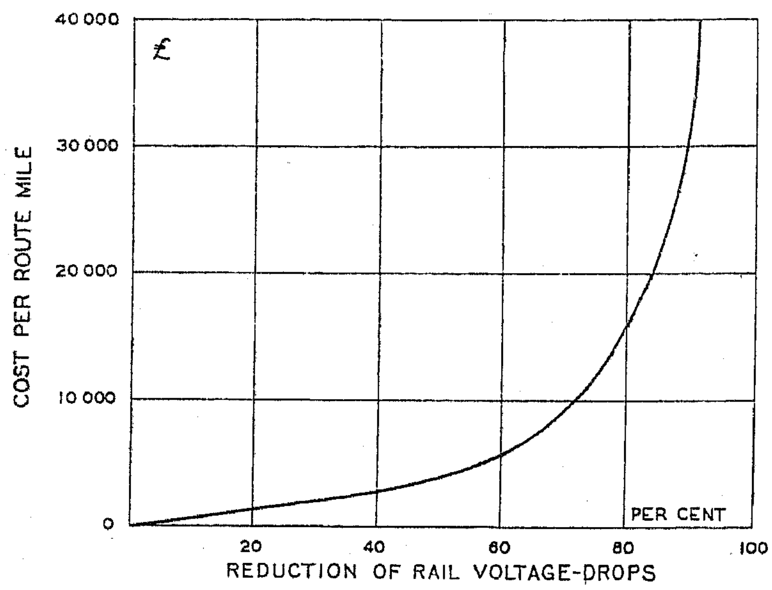

Fig. 12.—Cost of copper (at 1s. per lb.) to reduce rail potentials by the amount indicated for 1 mile of double track (102-lb. rails).

to consider the annual costs. The amount of copper required in the negative feeders will depend upon the amount of resistance in the local negative feeder. On the assumptions, as regards cost of copper and energy, mentioned above, a case has been worked out for two permissible maximum rail gradients (Fig. 13). Apart

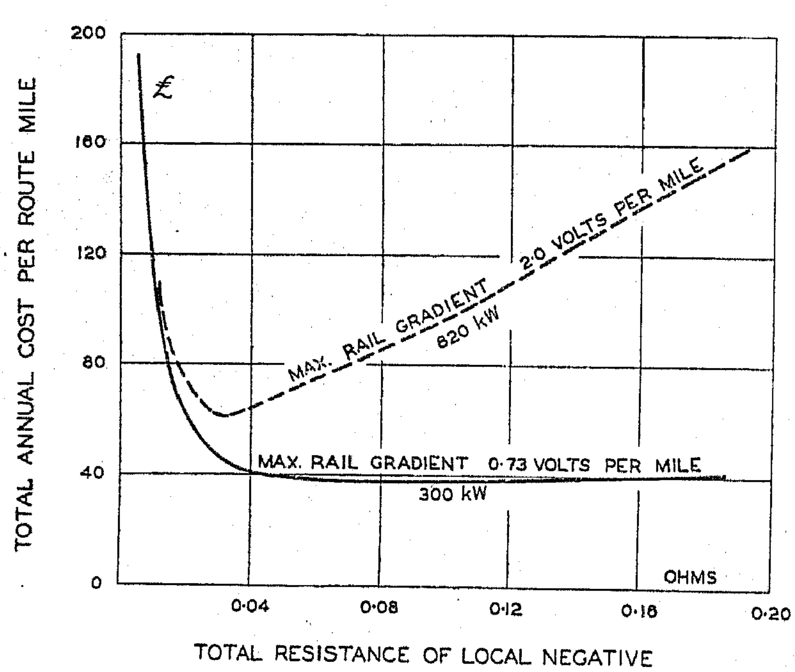

Fig. 13.—Annual cost of reducing existing rail potentials by 50 per cent.

from the local negative, one other feeder is installed on each track radiating from the substation.

Enough has been said to indicate how expensive mitigative measures become, if applied only to the traction network. It must also be pointed out that expenditure as indicated above is a dead loss to the traction authority. Moreover, although rail potential-gradients are reduced thereby, the installation of negative feeders widens the area over which damage may occur and leads to greater operating instability.

The cost of insulating coverings is, of course, high and is a loss to the owners of conduits, but where soil corrosion is present insulated coverings become necessary in any case.

Conclusion.

It has been possible only to outline this important subject, which is far too complex for accurate quantitative generalization. As yet it is too soon to be able to predict, with absolute certainty, the consequences of any proposed mitigative measures. The results achieved by the method of approach outlined in this paper justify the claim that the problem is capable of solution at reasonable expense. Such solution, it is felt, is best attained by regarding the matter from the broadest point of view, as when the investigations are guided by an independent engineer assisted by a co-operative committee.

The author would like to express his gratitude to the members of the committee with which he was associated in the work outlined in this paper, and to all those, both in Australia and elsewhere, who have materially contributed to his knowledge of this complex subject.

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DISCUSSION ON

"NOTE ON A DEMONSTRATION OF A LOW-VOLTAGE ELECTRON MICROSCOPE USING ELECTROSTATIC FOCUSING." *

Dr. W. Henneberg (Germany) (*communicated*): As the author is unable to obtain agreement between the observed and calculated values of the magnification of his electron microscope he concludes that the theory is capable of giving only a qualitative result. In fact, it is generally impossible to replace an electron lens, consisting of two *lochblendes*,† by two separate *lochblende* lenses; the accurate procedure‡ for the immersion objective must be followed in this case. An example of the procedure will be found later in this discussion. In many arrangements, including that of the author, agreement with the experimental data may nevertheless be reached by appropriate extension of the Davisson and Calbick§ formula for the focal length of a *lochblende*. When this formula was published no details were given of its derivation; a theoretical basis‖ for the formula has, however, been worked out as the result of investigations at the AEG research laboratory on problems of electron optics. A discussion of the formula will now be given.

The focal length f' is obtained from the expression

$$\frac{1}{f'} = \frac{1}{4\sqrt{V_b}}\int_{-\infty}^{\infty}\frac{V''}{\sqrt{V}}dz \quad . \quad . \quad . \quad . \quad (1)$$

in which the axis of z coincides with the axis of the lens (see Fig. A). Further, $V(z)$ indicates the potential on the axis in relation to the cathode (i.e. eV is the energy of an electron), while $V'' = d^2V/dz^2$, and the subscripts a and b denote values before and behind the lens respectively. Let the purely optical expressions f and f' denote the focal lengths on the object side and the image side respectively, and assume a positive value for the focal length when the focus is beyond the principal point in the direction of the rays. For the object side we therefore have the equation

$$\frac{1}{f} = \frac{1}{4\sqrt{V_a}}\int_{\infty}^{-\infty}\frac{V''}{\sqrt{V}}dz = \frac{-1}{4\sqrt{V_a}}\int_{-\infty}^{\infty}\frac{V''}{\sqrt{V}}dz \quad . \quad (1a)$$

Equation (1*a*) is formed from (1) by interchange of the object and image sides, i.e. of a and b, and of $-\infty$ and ∞. Equations (1) and (1*a*) directly yield the optical law

$$f : f' = -\sqrt{V_a} : \sqrt{V_b} = -\mu : \mu'$$

for the refractive index μ is proportional to the square root of the potential. To convert to the equation of Davisson and Calbick for the focal length of the *lochblende*, the integral must be evaluated. It is here possible to approximate by putting V_0 instead of V, where V_0 is the value of V taken at a point where V'' is considerably above or below zero, i.e. the value at the lens. Then

$$f' = \frac{4\sqrt{(V_b V_0)}}{V_b' - V_a'} \quad . \quad . \quad . \quad . \quad . \quad (2)$$

If, in particular, the lens is thin, the Davisson and Calbick formula is obtained by putting $V_b \approx V_0$. Then

$$f' = \frac{4V_0}{V_b' - V_a'} \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

The equation corresponding to (2) is

$$f = \frac{-4\sqrt{(V_a V_0)}}{V_b' - V_a'} \quad . \quad . \quad . \quad . \quad (2a)$$

* Paper by Mr. W. E. BENHAM (see vol. 75, p. 388).

† The German word *lochblende* is not translated, since the term "an aperture in a charged conducting plate" is somewhat elaborate, while "lens" does not provide a sufficiently precise definition.

‡ E. BRÜCHE and O. SCHERZER: "Geometrische Elektronenoptik" (Berlin, 1934), chap. II, 10.

§ C. J. DAVISSON and C. J. CALBICK: *Physical Review*, 1931, vol. 38, p. 585, 1932, vol. 42, p. 480.

‖ O. SCHERZER: *Zeitschrift für Physik*, 1933, vol. 80, p. 193; also see E. BRÜCHE and O. SCHERZER: *loc. cit.*, chap. II, 7. In addition, the present author's very interesting suggestion regarding the assembly of a cathode of various materials, with the object of comparing the specific emissions of each part, has already been carried out. Speaking before the German Physikertag at Pyrmont in September 1934, J. Pohl reported on experiments in which he illuminated with a quartz lamp a cathode assembled of various metals. He then produced an image of the cathode with the aid of the photo-electrons. An account of this investigation will appear shortly in *Zeitschrift für technische Physik.*

The results obtained by the use of formulæ (2) and (2*a*), instead of the single formula (3) as employed by the author, accord well with the outcome of experiment. This is because account is taken of the difference between the refractive indices $\sqrt{V_a}$ and $\sqrt{V_b}$ before and behind the lens. To show this we must first define the (constant) refractive index before and behind the lens; in electron optics this amount is generally variable. Three spaces—(1), (2), and (3)—are bounded by the cathode C, the screen S, and the two lenses L_1 and L_2 (Fig. A). Let the potential of the cathode be zero, those of the lenses V_1 and V_2, and that of the screen V_s. It is then reasonable to give the following values as the potentials of the spaces (1), (2), and (3):—

$$V_{(1)} = \tfrac{1}{2}V_1;\ V_{(2)} = \tfrac{1}{2}(V_1 + V_2);\ V_{(3)} = \tfrac{1}{2}(V_2 + V_s) \qquad (4)$$

If we desired to allow for the variability of the refractive index, we could not regard the system as consisting of two lenses L_1 and L_2, nor employ the corresponding optical laws. According to (4) and (2), for example, the focal length f_1' of the first lens L_1 may be written

$$f_1' = \frac{4\sqrt{[V_{(2)}V_{(1)}]}}{V'_{(2)} - V'_{(1)}}$$

The formulæ for the optical dimensions will now be extended so as to include the case of various refractive

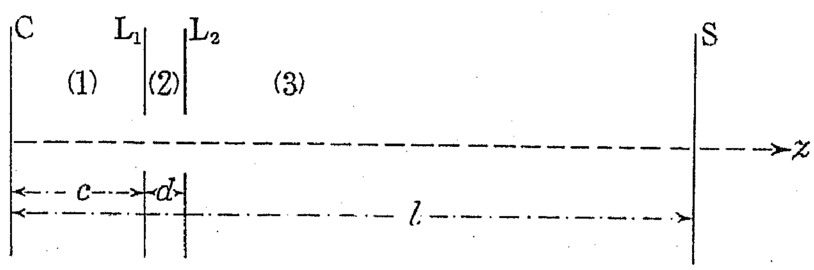

FIG. A.

indices, the system of lenses being considered as a whole.* We have

$$\left.\begin{array}{l} \text{Focal lengths: } f = -f_1f_2/k,\quad f' = f_1'f_2'/k; \\ \text{Principal points: } L_1H = -df_1/k,\quad L_2H' = -df_2'/k; \\ \text{Distance between principal points:} \\ \qquad HH' = d[f_1 + f_1' - (f_2 + f_2') - d]/k, \\ \text{where } k = f_1' - f_2 - d \end{array}\right\} (5)$$

Here f_1 and f_1' are the focal lengths of the first lens, f_2 and f_2' are those of the second lens, and d is the distance L_1L_2. The dimensions of such a system are determined by equations (2), (4), and (5), provided that the potentials V_1 and V_2 and the distances $L_1L_2(= d)$ and $CL_1(= c)$ are known.† The magnification is calculated from the formula $M = F'S/f'$, in which we can generally write $F'S \approx L_2S$; for in most cases $L_2S >> L_2F'$. Instead of L_2S we now use the dimension $l = CS(L_2S = l - d - c)$.

Example 1.—In the author's experiment, $V_1 = 100$ volts, $V_2 = 1\,000$ volts, $c = 2{\cdot}38$ mm, $d = 5{\cdot}0$ mm, and $l \approx 310$ mm. Therefore, from (2), $f_1 = -2{\cdot}05$ mm, $f_1' = 6{\cdot}80$ mm, $f_2 = 16{\cdot}4$ mm, and $f_2' = -22{\cdot}2$ mm. Thus the focal length of the system considered as a whole becomes $f' = 10{\cdot}5$ mm, and the magnification $M = 300/10{\cdot}5 = 29$, which closely agrees with the approximate value $M = 30$, found by experiment.

Although the above proves the practicability of the focal-length formula, another example will be quoted whose principle is important. If we insert a grid at potential V_1 between the cathode and the first lens, and form an image of it, the conditions will be particularly simple; for the refractive indices before and behind the lens are now the same, and are therefore independent of definition (4).

Example 2.—Taking the data of such an arrangement from the experiments of Hess,* we have $V_1 = 500$ volts, $V_2 = 2\,700$ volts, $c = 13$ mm, $d = 7$ mm, $l = 377$ mm. Thus $f' = 17{\cdot}8$ mm, and therefore the magnification is $M = 360/17{\cdot}8 = 20$, agreeing exactly with the experimental result.

Applying the same method to Johannson's measurements on an immersion objective with two closely neighbouring lenses,† the dimensions $V_1 = 75$ volts, $V_2 = 750$ volts, $c = 1{\cdot}1$ mm, $d = 1{\cdot}05$ mm, and $l = 240$ mm, give a magnification of 130 instead of the actual value of 58. The disagreement between theory and experiment here is due to the fact that the electrostatic field $V'_{(2)}$ is very large $V'_{(2)} \approx 10V'_{(1)}$. On treating the immersion objective with a greater degree of accuracy, however, close agreement with the experimental result was obtained,‡ the magnification being found to be 55.

Summarizing the above, it has been shown that, under certain circumstances, the formulæ for the focal length of a *lochblende* are suited for calculating the magnification attained with the electron microscope using electrostatic focusing.

Mr. W. E. Benham (*in reply*): I should like to thank Dr. Henneberg for his remarks. It is very satisfactory to have established that the variable refractive index may usually be allowed for by defining the potentials of the spaces as the mean of the two boundary values, and that my data and those of Hess may be reconciled with theory on this basis.

Dr. Henneberg does not refer explicitly to the electrostatic complications which must arise in cases where the apertures (*lochblende*) are of diameter comparable with the electrode separation. I am not aware that any solution for the (par-) axial electric field between two co-axial apertured discs, taking into account the finite aperture size, has as yet been proposed. One would expect a fairly large correction for aperture size to be necessary in the case of the Johannson measurements where the disc separation was of the order of 1 mm only, while in my experiment one might expect some correction to be required, since the aperture diameter was of the same order as the disc separation. In the absence of a complete solution of the electrostatic problem it is impossible to predict the importance of the aperture correction, and meanwhile one must infer from the interesting work of Dr. Henneberg that in two typical cases the aperture correction is likely to be too small to disturb unduly the agreement which follows as a result of his admirable treatment of the refractive-index correction.

* For example, see M. BORN: "Optik" (Berlin, 1933), para. 24.

† In the systems referred to in this discussion, $V_s = V_2$; i.e. $V_{(3)} = V_2$, and $V'_{(3)} = 0$.

* *Zeitschrift für Physik*, 1934, vol. 92, p. 274.

† *Annalen der Physik*, 1933, vol. 18, p. 385.

‡ E. BRÜCHE and O. SCHERZER: *loc. cit.*

THE USE OF THE GRASSOT FLUXMETER AS A QUANTITY METER: ITS APPLICATION TO THE DETERMINATION OF THE MOMENT OF INERTIA OF A SMALL DIRECT-CURRENT ARMATURE.*

By E. W. Golding, M.Sc.Tech., Associate Member.

(*Paper received* 8*th January*, 1934.)

Summary.

The question of the measurement of the quantity of electricity passed through a circuit in a given time is intimately connected with the magnitude of this time of passage. The paper describes the use of a Grassot fluxmeter for such measurements and gives the theory of the instrument when so used. It is shown that this instrument provides a useful intermediary when the time of passage is such that neither the ballistic galvanometer nor the ampere-hour meter can be used successfully.

The determination of the moment of inertia of a small d.c. armature, using a fluxmeter, is described, and the results obtained are verified by two alternative methods of determination.

Table of Contents.

(1) Introduction.

The ampere-hour meter and the ballistic galvanometer are both instruments which have been used successfully for many years as measurers of quantities of electricity. Each has its limitations, however, when considered from the point of view of the time taken to supply the quantity to be measured. Thus, the ampere-hour meter is designed, and commonly used, for the measurement of a quantity of electricity supplied over a period of a number of hours, whereas the ballistic galvanometer can only be used successfully when the quantity is supplied during a small fraction of a second.

In cases where the time of supply is (say) several seconds, and especially when the current during this time is small, neither of the above methods of measurement is suitable.

Even when an ampere-hour meter of a low current rating is chosen for such a measurement, the current supplied may still constitute only a very low load on the meter and it is well known that the errors of such meters at low loads are considerable. The necessity for an exceedingly small starting current, a linear speed/current characteristic, and some means of observing fractions of a revolution of the disc, is likely to render the use of such meters quite out of the question if accurate measurements are required under these conditions.

In the case of the ballistic galvanometer the theory of the instrument, as usually stated, depends upon the fact that the time of supply of the quantity to be measured is very small.

It is suggested here that the Grassot fluxmeter may be used as a quantity meter when the time of supply of the quantity is such as to be too small for the successful use of an ampere-hour meter and too long for the ballistic galvanometer to be used.

(2) Method of Use.

Referring to Fig. 1, the fluxmeter is shown connected across the potential terminals of a low-resistance shunt R_s which carries the quantity of electricity to be measured.

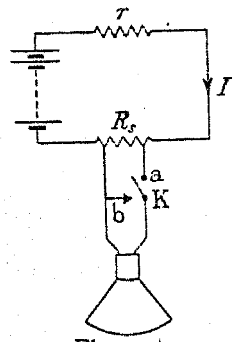

Fig. 1.

K is a double-contact key for the purpose of short-circuiting the fluxmeter when not in use and so bringing its movement quickly to rest by the electromagnetic damping action. This key should be so designed that the short-circuit path has a very low resistance compared with R_s.

At the beginning of the time-interval during which the quantity of electricity passed is to be measured, the key K is closed on contact "a." At the end of the interval the key is moved on to contact "b," so that the fluxmeter is short-circuited both at the beginning and end of the period.

The deflection of the fluxmeter, when multiplied by a

* The Papers Committee invite written communications, for consideration with a view to publication, on papers published in the *Journal* without being read at a meeting. Communications, except those from abroad, should reach the Secretary of the Institution not later than one month after publication of the paper to which they relate.

constant depending upon the constant of the fluxmeter itself and upon the resistance of the shunt R_s, gives the quantity of electricity passed through the shunt in the period of time between the closing and opening of the key K. Since the key, on contact "b," will not provide a completely resistance-less short-circuit path, the fluxmeter deflection may continue to increase slowly after the key has been moved off contact "a." The final reading required is that at the instant when the key is moved over to contact "b," any further deflection after this instant being unimportant.

(3) Theory of Action.

Let I = current in main circuit (see Fig. 1),
i = current in fluxmeter circuit at any time during the measuring period,*
e_f = e.m.f. induced in the fluxmeter coil due to its movement in the permanent-magnet field of the instrument,
R_s and L_s = resistance and inductance of the shunt,
R and L = resistance and inductance of the fluxmeter circuit, and
e_s = e.m.f. across the shunt at any instant.

Then

$$e_s = R_s(I - i) + L_s\frac{d}{dt}(I - i)$$

and $e_f = K\dfrac{d\theta}{dt}$, where K is a constant depending upon the construction of the fluxmeter.

The voltage equation of the fluxmeter when in motion is thus

$$e_s = e_f + L\frac{di}{dt} + Ri$$

or

$$R_s(I - i) + L_s\frac{d}{dt}(I - i) = K\frac{d\theta}{dt} + L\frac{di}{dt} + Ri$$

Now the voltage-drop Ri in the fluxmeter circuit is so small as to be negligible, since i is very small.

For the same reason, $I - i \doteqdot I$.

$$\therefore\ R_sI + L_s\frac{dI}{dt} = K\frac{d\theta}{dt} + L\frac{di}{dt} \text{ very closely.}$$

Integrating with respect to t, we have

$$\int_0^T\left(R_sI + L_s\frac{dI}{dt}\right)dt = \int_0^T K\frac{d\theta}{dt}dt + \int_0^T L\frac{di}{dt}dt$$

where T is the time interval during which the quantity of electricity to be measured is passed.

$$\therefore\ R_s\int_0^T Idt + L_s\int_{I_1}^{I_2} dI = K\int_{\theta_1}^{\theta_2} d\theta + L\int_{i_1}^{i_2} di$$

I_2 and I_1 are the final and initial values of current in the main circuit; i_2 and i_1 are corresponding values in the fluxmeter circuit; while θ_2 and θ_1 are the final and initial values of the fluxmeter deflection.

* Both I and i may be variable.

From the above we have

$$R_s\int_0^T Idt + L_s(I_2 - I_1) = K(\theta_2 - \theta_1) + L(i_2 - i_1)$$

Now i_2 and i_1 are both zero, so that the term $L(i_2 - i_1)$ is zero. The term $L(I_2 - I_1)$ may not be zero but is usually small compared with the term $R_s\int_0^T Idt$. If a non-inductive shunt is used this term is entirely negligible.

Thus, finally,

$$R_s\int_0^T Idt = K(\theta_2 - \theta_1)$$

or, the quantity of electricity to be measured—$\int_0^T Idt$—is given by $\dfrac{K}{R_s}(\theta_2 - \theta_1)$.

Briefly, the action is that the fluxmeter coil rotates at such a speed that the e.m.f. e_f, induced in it as it cuts through the permanent-magnet field of the instrument, is equal to the applied e.m.f. e_s at all instants.

(4) Units.

Under the above conditions the instrument is acting as a volt-second meter (magnetic flux and volt-seconds being the same dimensionally). By dividing the measured quantity by the resistance R_s we have the required value of ampere-seconds.

Reverting to fundamental principles of e.m.f. induction we have, in the case of a single-turn circuit,

$$\frac{\text{Flux cut per second}}{10^8} = \text{volts}$$

or

$$\frac{\text{Flux}}{10^8} = \text{volts} \times \text{seconds}$$

If, now, k = flux cut per unit deflection of the fluxmeter when the search coil used has a single turn; then $\dfrac{k}{10^8}$ = volt-seconds per unit deflection, or $\dfrac{k}{10^8R_s}$ = ampere-seconds per unit deflection.

Hence quantity of electricity in ampere-seconds

$$= \frac{k}{10^8R_s} \times \text{fluxmeter deflection}$$

A representative value of k in the case of the fluxmeter is 15 000. Hence, if a shunt of resistance 0·001 ohm is used, a quantity of 10 ampere-seconds discharged through the shunt would give a deflection of

$$\frac{10 \times 10^8 \times 0\cdot001}{15\ 000} = 66\cdot6 \text{ divisions.}$$

It is obvious that before a measurement is made the shunt must be so chosen as to have a resistance suitable to the quantity to be measured. In this connection it may not always be most convenient, from the point of view of observing the reading of the fluxmeter, to aim at the largest possible deflection. Obviously, the larger the

shunt the greater the deflection in the given interval of time. Too high a value of the shunt resistance may render observation difficult owing to the speed with which the fluxmeter pointer moves over the scale. For this reason it may be more convenient to aim at a smaller deflection with, consequently, a slower movement.

(5) Experimental Verification.

With the object of verifying the above theory several experiments were made using a fluxmeter which had a constant, k, of 15 000 as stated in the preceding paragraph.

A non-inductive shunt of resistance 0·001 ohm was used and the same quantity of electricity—namely 10 ampere-seconds—was passed through the shunt in a number of different times, such as 10 seconds (current = 1 amp.); 20 seconds (current = 0·5 amp.), and so on.

From the example previously given it will be seen that a fluxmeter deflection of 66·6 divisions should have been obtained in all cases. The results actually obtained are shown graphically in Fig. 2, in which fluxmeter deflection is plotted against the time taken to discharge the 10 ampere-seconds through the shunt. When making the observations it was found that quite consistent readings could be obtained, with an accuracy easily within 1 per cent, provided the time of discharge was less than about 200 seconds. With longer periods of discharge the behaviour of the instrument was much less consistent.

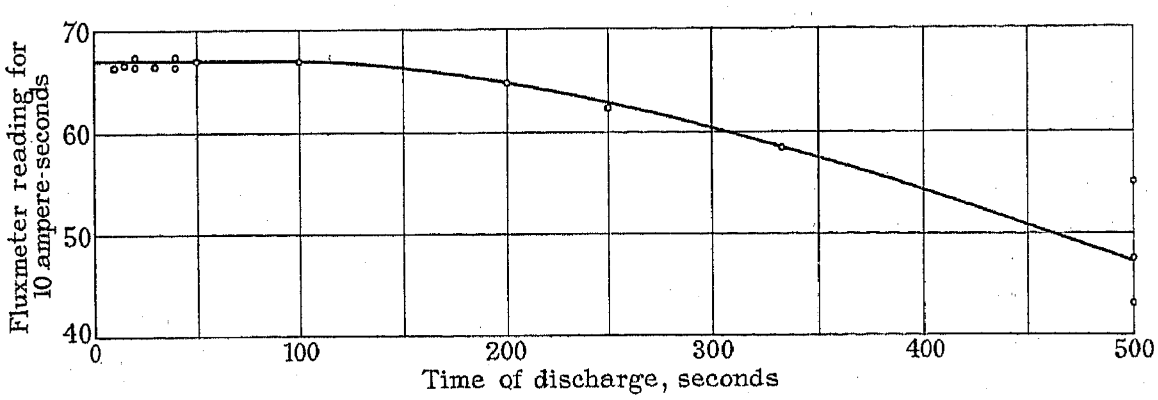

Fig. 2.

It will be seen from this graph that the instrument can be used successfully for such measurements, provided the time of discharge is less than about 3 minutes. For times longer than this the movement of the fluxmeter is too slow for the simple theory as outlined above to hold.

This time-interval (3 minutes) is, however, sufficiently long for the fluxmeter to form a useful intermediary between the ballistic galvanometer and the ampere-hour meter for quantity measurement. If the time of discharge is longer than 3 minutes the ampere-hour meter can be used successfully for the measurement, the fluxmeter method being no longer necessary.

As additional verifications the effect of inductance in the fluxmeter circuit and of variation of the current I in the main circuit during the measuring time-interval were observed.

It was found that the insertion of an inductance of several millihenrys in the fluxmeter circuit had no observable effect. As a check on the effect of variation of the current I during the period of measurement, a quantity of 10 ampere-seconds was discharged through the shunt, this quantity being made up by 0·5 ampere for 10 seconds, followed immediately by 0·25 ampere for 20 seconds. A reading of 66·5 divisions was obtained, showing that such variation of current made no observable difference to the reading.

(6) Application to the Measurement of the Moment of Inertia of a Small Direct-Current Armature.

A useful application of this method of measuring a quantity of electricity is in the determination of the moment of inertia of the armature of a direct-current machine by an electrical method due to Dr. J. C. Prescott.* In this method, which is a development of a method due to Kapp, an increment of voltage is first applied to, and then removed from, the armature terminals of the machine whilst it is running. The quantities of electricity supplied to the armature during the consequent accelerating and retarding periods are measured by an ampere-hour meter. The armature is supplied, through a variable resistance, from a battery, a switch being included in the circuit for the purpose of suddenly increasing or reducing the applied battery voltage. The field current of the machine is supplied from a separate source and is kept at the normal value throughout. If the resistance in the armature circuit is adjusted, together with the increment of voltage from the battery, so that the number of revolutions made by the armature when accelerating is equal to the number of revolutions made in the same time when decelerating, the moment of inertia of the armature is given by

$$\mathbf{I} = \frac{F}{6\cdot 26(\overline{\omega}_1 + \overline{\omega}_2)}\left\{Q_1 - Q_2\right\} \text{ kg-m}^2$$

where F = the induction factor of the machine (i.e. generated voltage per revolution per second), $\overline{\omega}_1$ and $\overline{\omega}_2$ are the changes in angular velocity (in radians per second) during the accelerating and retarding periods respectively, and Q_1 and Q_2 are the measured quantities of electricity (in ampere-seconds) during the accelerating and retarding periods respectively.

Now, in the illustrative experiment described in Dr. Prescott's paper the machine used was a 100-volt, 14-kW generator, having a comparatively large moment of inertia of 3 kg-m^2. In such a case the quantities Q_1 and Q_2 may be measured quite satisfactorily by an ampere-hour meter. In the determination of moment of

* *Journal I.E.E.*, 1931, vol. 69, p. 1179.

*

inertia described here, however, the machine used was a 220-volt, 5-h.p. shunt motor having a moment of inertia much smaller than 3 kg-m^2.

In this case the quantities Q_1 and Q_2 are so small, and the accelerating and retarding periods so short, that satisfactory measurements by an ampere-hour meter are rendered very difficult, if not impossible.

In such a case, therefore, the fluxmeter method serves a useful purpose.

(7) Determination of Moment of Inertia by Fluxmeter Method.

Data for the machine (experimentally determined) and the results obtained using the fluxmeter method are given below:—

Armature resistance	1·13 ohms
Induction factor (F) with normal field current	8·76
Battery voltages applied to the armature ..	14 and 26 (giving an increment of 12 volts)
Resistance in series with the armature for equal numbers of revolutions during equal accelerating and retarding periods ..	30·85 ohms
Armature current at the higher speed ..	1·0 amp.
Armature current at the lower speed ..	0·8 amp.
Q_1	3·3 amp.-seconds
Q_2	1·8 amp.-seconds
Resistance of non-inductive shunt used with fluxmeter	0·001 ohm
k for fluxmeter	15 000
$\overline{\omega}_1$	6·61 radians per second
$\overline{\omega}_2$	6·59 radians per second

Hence
$$\mathbf{I} = \frac{8\cdot76 \times (Q_1 - Q_2)}{6\cdot26 \times (\overline{\omega}_1 + \overline{\omega}_2)}$$
$$= \frac{8\cdot76 \times 1\cdot5}{6\cdot26 \times 13\cdot2} = 0\cdot159 \text{ kg-m}^2$$

The total accelerating and retarding periods with the applied armature voltages used were of the order of 5 seconds. The two equal periods chosen for the purpose of the experiment were 3 seconds, during which, with the armature series resistance adjusted to 30·85 ohms, the armature made equal numbers of revolutions—namely, $6\frac{1}{2}$ revolutions—both accelerating and retarding.

The time and number of revolutions being so small it was found necessary, in order to obtain sufficiently accurate results, to use a chronograph in conjunction with a wiping contact attached to the armature shaft, contact being made once every revolution.

The essential parts of the chronograph were two pens, operated by two small electromagnets, the pens making indications on a strip of paper moving under them. The paper strip was motor-driven at a uniform speed. With the arrangement used, one pen was operated by the contact on the armature shaft while the other was operated from a separate circuit containing a key so that it could be kept deflected for the 3 seconds during which observations were being made. By this means it was possible to obtain the time for each revolution during the accelerating and retarding periods as well as the steady speeds corresponding to the two steady applied armature voltages.

It was thus found very useful in the adjustment of the armature series resistance to give equal numbers of revolutions in equal accelerating and retarding periods, and also in the determination of the induction factor F.

(8) Determination of the Moment of Inertia by the Kapp Method.

This method was used as a check upon the fluxmeter determination, not because of its greater accuracy, but rather for the reason that all the data required were made available from the chronograph records mentioned above. It consists in plotting first of all the acceleration

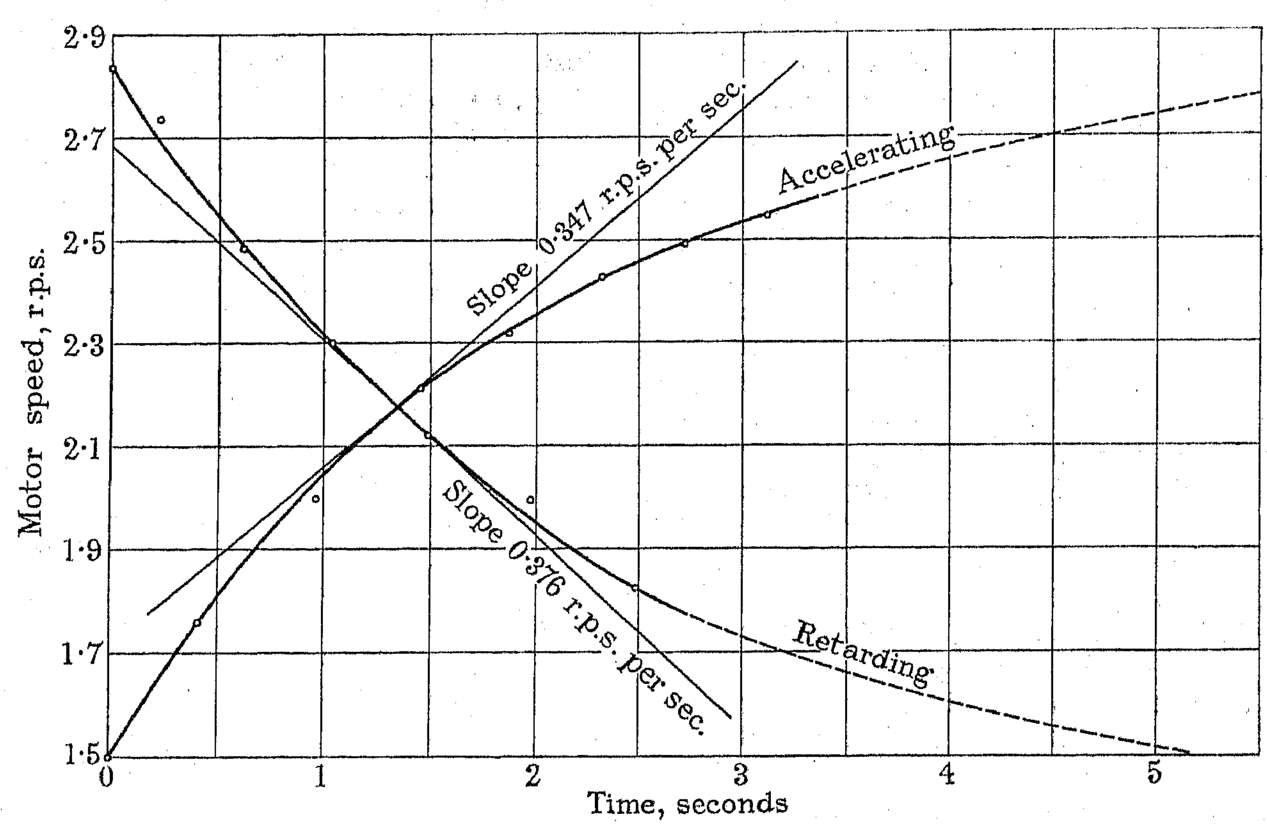

Fig. 3.

and retardation curves of the armature for a given incremental voltage applied to and removed from it. These curves for the armature in question are shown plotted in Fig. 3, the experimental results described in the previous paragraph being used for the purpose. Tangents are now drawn to the curves at their point of intersection. The moment of inertia is then given by

$$\mathbf{I} = \frac{F(i_1 - i_2)}{4\pi^2\left[\left(\frac{dN}{dt}\right)_1 + \left(\frac{dN}{dt}\right)_2\right]}$$

where i_1 and i_2 are the armature currents, at the time corresponding to the point of intersection of the curves, when accelerating and retarding respectively.

$\left(\frac{dN}{dt}\right)_1$ and $\left(\frac{dN}{dt}\right)_2$ are the slopes of the curves at the point of intersection (both reckoned as positive).

The difference $(i_1 - i_2)$, as experimentally determined, was 0·52 amp., while the slopes at the point of intersection of the curves were 0·347 and 0·376.

$$\therefore \mathbf{I} = \frac{0 \cdot 52 \times 8 \cdot 76}{(0 \cdot 347 + 0 \cdot 376) \times 4\pi^2} = 0 \cdot 158_9 \text{ kg-m}^2$$

(9) Determination of Moment of Inertia by Bifilar Suspension.

As a more definite check on both of the above methods, the armature was removed from the machine and its moment of inertia was determined very carefully by the well-known method of bifilar suspension.

The results obtained were:—

Weight of armature = 85 lb. (38·55 kg).
Distance apart of suspending strings = 11 in. (0·28 m).
Length of suspending strings = 14 ft. $9\frac{3}{4}$ in. (4·52 m).
Time of swing = $1 \cdot 96_6$ seconds.
(Average of six observations of the time of 50 very small swings.)

Thus the moment of inertia by this method is given by

$$\mathbf{I} = \frac{9 \cdot 81 \times 0 \cdot 14^2 \times 1 \cdot 966^2}{4\pi^2 \times 4 \cdot 52} \times 38 \cdot 55$$
$$= 0 \cdot 159_8 \text{ kg-m}^2$$

(10) Conclusion.

Summarizing the determination of moment of inertia by the three methods described, we have:

(1) By fluxmeter method	.. ..	0·159 kg-m^2
(2) By Kapp method	.. ..	$0 \cdot 158_9$ kg-m^2
(3) By bifilar suspension	.. ..	$0 \cdot 159_8$ kg-m^2

As these results show an agreement to well within 1 per cent, the fluxmeter method of measurement may be considered to be sufficiently checked by the other two methods. It should be pointed out, however, that a less careful determination of the induction factor F of the machine may have introduced appreciable discrepancies between the results, since the values obtained in the two electrical methods both depend directly upon this factor.

In conclusion, the author wishes to express his thanks to Mr. G. Parsons, laboratory steward of the Electrical Engineering Department at University College, Nottingham, in which the experimental work was carried out, for his assistance in making many of the laboratory measurements.

PROCEEDINGS OF THE INSTITUTION.

872nd ORDINARY MEETING, 25th OCTOBER, 1934.

Mr. P. V. Hunter, C.B.E., Past-President, took the chair at 6 p.m.

The minutes of the Annual General Meeting held on the 10th May, 1934, were taken as read and were confirmed and signed.

A list of candidates for election and transfer, approved by the Council for ballot, was also taken as read and was order to be suspended in the Hall.

The Chairman announced that, during the period May to September, 618 donations and subscriptions to the Benevolent Fund had been received, amounting to £539. A vote of thanks was accorded to the donors.

The Premiums (see vol. 74, page 602, and vol. 75, page 130) awarded for papers read or published during the past session were then presented by the chairman to such of the recipients as were able to be present.

Mr. Hunter then vacated the chair, which was taken by **Prof. W. M. Thornton, O.B.E., D.Sc., D.Eng.,** President, amid applause.

Prof. E. W. Marchant: I have to make a proposal which I am sure will meet with your unanimous commendation. It is that we should express our thanks to Mr. Hunter for his services as President during the past year. He has shown in dealing with difficult situations a quickness of resource which we have all recognized as one of his most outstanding qualities. He has also shown a thorough spirit of sportsmanship. He has tried to encourage the members of the Institution to play golf, and he even ventured to recommend it at our Annual Dinner. Moreover, in addition to attending the dinners and meetings of the Local Centres he has also taken part in their golf tournaments.

I do not want to occupy your time for too long, but I should like to refer to one other matter, namely, that during Mr. Hunter's period of office the Transmission Section of the Institution has been formed, which in the future, I think, we shall consider to be one of the biggest steps in the development of the Institution. It is, of course, peculiarly appropriate that such a step should have been taken during Mr. Hunter's presidency. We all admire Mr. Hunter for his qualities, and we all thank him most sincerely for the invaluable services which he has rendered to the Institution. It is with very great pleasure, therefore, that I move: "That the best thanks of the Institution be accorded to Mr. P. V. Hunter for the very able manner in which he has filled the office of President during the past year."

The resolution was seconded by **Lieut.-Col. K. Edgcumbe, T.D.,** and was carried with acclamation.

Mr. P. V. Hunter: I feel rather overwhelmed at the way in which the proposer and seconder of this motion have put the matter to you. I had at one time hoped that it would be possible to refer to the services I had been able to render in technical matters to the Institution in my year of office; but, as you all know, that is not really the work of a president. The duty of a president is to keep smiling and to keep things moving sweetly and smoothly, and in that respect I must say that the members of the Institution regard the President in such a way that he cannot but feel the greatest possible pleasure in his office and respect for the Institution and its members, and what they stand for.

I should like also to pay a very warm tribute to the permanent staff of the Institution, headed by Mr. Rowell. I feel it cannot be too often said to the general body of members what an admirable staff they have. On every occasion the staff does what is necessary and never attempts to rob the President of any halo. I will not detain you any longer, except to say that I have enjoyed every minute of my year of office, and I feel sure that Professor Thornton will be able to say the same thing when he comes to stand in my position next year. Thank you very much.

The President then delivered his Inaugural Address (see page 1).

Dr. A. Russell: I have great pleasure in proposing that the best thanks of the Institution be accorded to Professor Thornton for his Presidential Address. I have never listened to an address full of more original matter. It has provided us with a magnificent intellectual banquet.

I had occasion lately to look up the papers Professor Thornton has written, so, naturally, I turned up "Who's Who," and under "Publications" I found "Papers, chiefly electrical." This proved his modesty, but was not very helpful. I remember some of those papers, for instance his earlier papers on dielectric phenomena, which I found very difficult to follow until I had studied them several times, when I found them quite straightforward and very impressive. His paper on high-voltage measurements is of great importance in practice. He was the first to prove that the electrical ignition of gases is not a thermal process but essentially an electrical one. His paper on globular lightning contains the best explanation yet given of the phenomenon. His electrical inventions display great originality. His ionic wind voltmeter measures the highest voltages with high accuracy. He has also invented an ellipsoid voltmeter. In addition, his work in connection with mining is very valuable; he has invented, for example, several kinds of miners' lamps. In our President we have a wonderful combination of a mathematician, a physicist, an engineer, and a philosopher with a very kindly outlook on humanity. The Institution may well look forward to a happy and prosperous year under his guidance.

Mr. W. E. Highfield: It gives me the very greatest pleasure to second the vote of thanks to Professor Thornton for his admirable address. Dr. Russell has used such happy phrases in proposing the motion that my task must necessarily be a very brief one; but there is one point upon which I should like to lay stress, since the very great privilege of speaking to-night has been accorded to me. This vote of thanks conveys our great appreciation of the thoughtful and inspiring address to which we have just listened; but it also conveys a great deal more than that: it is an expression of deep admiration for our President, and a conveyance of our loyalty to him in the great task which he has taken on. I have great pleasure in seconding the motion.

The vote of thanks was then carried with acclamation, and, after the President had briefly replied, the meeting terminated at 7.30 p.m.

INSTITUTION NOTES.

Rules for Students' Sections.

The Council have approved a uniform set of Rules for Students' Sections to take the place of the respective sets of Rules under which the various Sections have hitherto been working. The uniform Rules, copies of which have been sent to all members of the Students' Sections, came into operation on the 1st January, 1935.

The Page Prize.

The Page Prize for 1934 has been awarded to Mr. J. H. Sprawson, Associate Member, for his thesis entitled "Experience and Conclusions on the Running of the Cape Town–Simonstown Electrification of the South African Railways."

Attendance of Visitors at Institution Meetings.

Members are reminded that, under the Bye-laws of the Institution, they are entitled to introduce one visitor at each Ordinary Meeting of the Institution. By the Council's direction, this applies also to the meetings of the Meter and Instrument Section, the Transmission Section, and the Wireless Section, and to the Informal Meetings.

Overseas Members and the Institution.

During the period 1st October to 31st December, 1934, the following members from overseas called at the Institution and signed the "Attendance Register of Overseas Members":—

Cunningham, B. T. (*Hong Kong*).
Gomes, J. V. M. (*Lisbon*).
Grey, W. J. (*Shanghai*).
Hext, Capt. F. M., R.E. (*Bangalore*).
Leary, J. F. (*Trinidad*).
Lovell, W. D. (*Ipoh, F.M.S.*).
Martin, G. E., M.A. (*Bombay*).
Phillips, W. A. G. (*New Delhi*).
Prescott, C. W. W. (*Sydney*).
Rudd, C. G., B.Sc. (*Auckland, N.Z.*)
Smith, H. F. (*Para, Brazil*).
Wardrop, G. G. (*Calcutta*).
Williamson, P. B., B.Sc. (*Matanzas, Cuba*).

Overseas Activities.

Calcutta.

At the inaugural meeting organized by the Local Committee, which was held at Calcutta on the 16th November, 1934, the Chairman (Mr. F. T. Homan) delivered an address of welcome to the 45 members present. The paper by Mr. H. W. Puttick entitled "The Electrical Work in connection with the Construction of the Willingdon Bridge, Calcutta" (see vol. 75, page 661), was then read and discussed.

New South Wales.

At the annual reunion of the New South Wales members held at Sydney on the 19th September, 1934, the number of members and guests present was 95. The new Chairman, Mr. E. F. Campbell, B.E., was officially welcomed by Mr. L. F. Burgess.

Queensland.

A social gathering of the Queensland members, and of representatives of kindred societies and other guests, the gathering numbering over 70 persons, was held at the Belle Vue Hotel, Brisbane, on the 19th October, 1934. An address of welcome was delivered by Mr. W. M. L'Estrange, the Local Hon. Secretary and Treasurer.

Local Committees Abroad.

The present constitution of the Local Committees abroad is as follows:—

AUSTRALIA.

NEW SOUTH WALES.

E. F. Campbell, B.Eng. (*Chairman*).
L. F. Burgess, M.C.
Sir John H. Butters, C.M.G., M.B.E.
R. V. Hall, B.E.
J. K. MacDougall.
W. J. McCallion, M.C.
V. L. Molloy.
P. S. Saunderson.
V. J. F. Brain (*Hon. Secretary*).

QUEENSLAND.

W. M. L'Estrange (*Chairman and Hon. Secretary*).
W. Arundell.
A. Boyd, D.Sc.
J. S. Just.
F. Walker.

SOUTH AUSTRALIA.

F. W. H. Wheadon (*Chairman and Hon. Secretary*).
E. V. Clark.
J. S. Fitzmaurice.
Sir W. G. T. Goodman.
W. Inglis.
P. Kennedy.
D. E. McLaren.

VICTORIA AND TASMANIA.

H. R. Harper (*Chairman and Hon. Secretary*).
F. W. Clements.
J. M. Crawford.
H. C. Newton.
T. P. Strickland.
R. J. Strike.

WESTERN AUSTRALIA.

J. R. W. Gardam (*Chairman*).
S. Johnson.
A. E. Lambert.
W. H. Taylor.
Prof. P. H. Fraenkel, B.E. (*Hon. Secretary*).

INDIA.

BOMBAY.

F. O. J. Roose (*Chairman*).
C. M. Cock.
R. G. Higham.
S. E. Povey.
H. J. Seale.
A. L. Guilford, B.Sc.Tech. (*Hon. Secretary*).

CALCUTTA.

F. T. Homan (*Chairman*).
N. C. Bhattarcharji.
C. R. Bland.
C. C. T. Eastgate.
A. R. Gundry.
P. S. E. Jackson.
S. W. Redclift.
H. G. Sale.
F. W. Sharpley.
K. G. Sillar (*Hon. Secretary*).

LAHORE.

F. L. Milne (*Chairman*).

G. K. M. Ambady, B.Sc. Tech.
A. T. Arnall.
J. C. Brown, B.Sc.
H. J. Darling.
Prof. T. H. Matthewman.
M. O. Sidiqui.

H. F. Akehurst (*Hon. Secretary*).

NEW ZEALAND.

F. T. M. Kissel, B.Sc. (*Chairman*).

R. H. Bartley.
M. C. Henderson.
E. Hitchcock.

C. Selwood Plank (*Hon. Secretary*).

SOUTH AFRICA.

TRANSVAAL.

W. Elsdon Dew (*Chairman and Hon. Secretary*).

J. B. Bullock.
S. E. T. Ewing.
V. Pickles.
B. Price.
Prof. O. R. Randall, Ph.D., M.Sc.
A. Rodwell.
L. B. Woodworth.

Committees, 1934-35.

Among the Committees appointed* by the Council for 1934-35 are the following:—

BENEVOLENT FUND COMMITTEE.

The President (*Chairman*).

A. H. M. Arnold, D.Eng.
J. R. Beard, M.Sc.
F. W. Crawter
V. Z. de Ferranti
W. McClelland, C.B., O.B.E.
Johnstone Wright
} representing the Council.

J. F. W. Hooper
P. Rosling
J. F. Shipley
} representing the Contributors.

And the Chairman of each Local Centre in Great Britain and Ireland.

INFORMAL MEETINGS COMMITTEE.

P. P. Wheelwright (*Chairman*).

G. F. Bedford.
H. Brierley.
S. B. Jackson.
A. N. D. Kerr.
F. C. Raphael.
A. F. W. Richards.
F. Jervis Smith.
M. Whitgift.

And

A representative of the General Purposes Committee.
The Chairman of the Papers Committee.
The Chairman of the London Students' Section.

JOINT COMMITTEE FOR NATIONAL CERTIFICATES AND DIPLOMAS IN ELECTRICAL ENGINEERING (ENGLAND AND WALES).

Prof. J. K. Catterson-Smith, M.Eng.
W. E. Highfield
Prof. E. W. Marchant, D.Sc.
} representing the I.E.E.

F. T. Chapman, D.Sc.
A. Morley, D.Sc.
H. J. Shelley, B.Sc.
} representing the Board of Education.

* The President is, *ex-officio*, a member of all Committees of the Institution.

JOINT COMMITTEE FOR NATIONAL CERTIFICATES AND DIPLOMAS IN ELECTRICAL ENGINEERING (SCOTLAND).

Prof. G. W. O. Howe, D.Sc.
D. S. Munro
R. Robertson, B.Sc.
Prof. S. Parker Smith, D.Sc.
} representing the I.E.E.

Dr. J. S. W. Boyle
J. G. Frewin
W. Hyslop
F. W. Michie
} representing the Scottish Education Department.

LOCAL CENTRES COMMITTEE.

A. P. M. Fleming, C.B.E., M.Sc.
F. Gill, O.B.E.
J. S. Highfield.
A. L. Lunn.
E. W. Moss.
Col. Sir Thomas F. Purves, O.B.E.
J. W. Thomas, LL.B., B.Sc.Tech.

And the Chairman of each Local Centre and Sub-Centre.

METER AND INSTRUMENT SECTION COMMITTEE.

Prof. J. T. MacGregor-Morris (*Chairman*).
W. Lawson (*Immediate Past-Chairman*).

T. S. Andrew.
H. P. Bramwell.
B. S. Cohen, O.B.E.
O. Howarth.
S. James.
B. H. Leeson.
H. B. Nield.
E. H. Rayner, M.A., Sc.D.
E. S. Ritter.
G. F. Shotter.
H. C. Turner.
J. G. Wellings.

And

A representative of the Council.
The Chairman of the Papers Committee.

OVERSEAS ACTIVITIES COMMITTEE.

N. Ashbridge, B.Sc.(Eng.).
Lieut.-Col. K. Edgcumbe, T.D.
G. Hendrey.
J. M. Kennedy.
C. Le Maistre, C.B.E.

C. C. Paterson, O.B.E.

And

The Chairman of the Finance Committee.
The Chairman of the General Purposes Committee.
The Chairman of the Membership Committee.
The Chairman of the Papers Committee.

Also the following co-opted members:—

Prof. J. K. Catterson-Smith, M.Eng.
W. P. Gauvain.
F. Gill, O.B.E.
A. S. Herbert.
A. C. Kelly.
F. Lydall.
J. T. Mertens.
E. A. Mills.
H. Nimmo.
E. E. Sharp.
A. L. Stanton.
C. S. Taylor.
V. Watlington, M.B.E.

SCHOLARSHIPS COMMITTEE.

Prof. J. K. Catterson-Smith, M.Eng.
W. H. Eccles, D.Sc., F.R.S.
Prof. J. T. MacGregor-Morris.
Prof. E. W. Marchant, D.Sc.
H. Marryat.
R. W. Paul.
Prof. E. L. E. Wheatcroft, M.A.

Johnstone Wright.

"SCIENCE ABSTRACTS" COMMITTEE.

L. G. Brazier, Ph.D., B.Sc.
Prof. J. T. MacGregor-Morris.
C. C. Paterson, O.B.E.
R. S. Whipple.

And	*Representing*
J. H. Awberry, B.Sc.	Physical Society.
A. Ferguson, M.A., D.Sc.	Physical Society.
D. Owen, B.A., D.Sc.	Physical Society.
Prof. G. F. J. Temple, D.Sc., Ph. D.	Physical Society.
Prof. G. P. Thomson, M.A., F.R.S.	Royal Society.

SHIP ELECTRICAL EQUIPMENT COMMITTEE.

A. G. S. Barnard.
Major B. Binyon, O.B.E., M.A.
J. H. Collie.
Dr. P. Dunsheath, O.B.E., M.A.
S. Harcombe, M.A., B.Sc.
A. Henderson.
J. F. W. Hooper.
P. V. Hunter, C.B.E.
J. W. Kempster.
A. E. Laslett.
A. Cecil Livesey.
W. McClelland, C.B., O.B.E.
S. W. Melsom.
J. F. Nielson.
N. W. Prangnell.
Col. A. P. Pyne.
T. A. Sedgwick.
H. D. Wight.
Ernest T. Williams, O.B.E.

And	*Representing*
W. McAuslan	Board of Trade.
W. T. Williams, O.B.E.	Board of Trade.
B. Hodgson	British Corporation Register of Shipping and Aircraft.
T. R. Thomas	British Corporation Register of Shipping and Aircraft.
W. Cross	Electrical Contractors' Association.
(To be nominated)	Electrical Contractors' Association of Scotland.
J. F. Nielson	Institution of Engineers and Shipbuilders in Scotland.
W. J. Belsey	Institution of Naval Architects.
S. F. Dorey, D.Sc.	Lloyd's Register of Shipping.
G. O. Watson	Lloyd's Register of Shipping.
A. B. Stewart	Lloyd's Underwriters' Association.
W. S. Wilson	North-East Coast Institution of Engineers and Shipbuilders.

TRANSMISSION SECTION COMMITTEE.

Chairman: R. Borlase Matthews.
Vice-Chairman: W. Fennell.

H. J. Allcock, B.Sc.(Eng.).
J. H. C. Brooking.
J. M. Donaldson, M.C.
Dr. P. Dunsheath, O.B.E., M.A.
J. L. Eve.
B. Handley.
P. V. Hunter, C.B.E.
C. F. Mounsdon.
Major T. Rich, O.B.E.
R. J. J. Swan.
W. A. Turnbull.
Johnstone Wright.

And

A representative of the Council.
The Chairman of the Papers Committee.
The following representatives of Government Departments:—

Central Electricity Board: C. W. Marshall, B.Sc.
Electricity Commission: J. M. Kennedy.
Post Office: P. J. Ridd.

WIRELESS SECTION COMMITTEE.

Chairman: S. R. Mullard, M.B.E.
Vice-Chairman: T. Wadsworth, M.Sc.
Immediate Past-Chairman: G. Shearing, O.B.E., B.Sc.

N. Ashbridge, B.Sc.(Eng.).
A. J. Gill, B.Sc.(Eng.).
N. F. S. Hecht.
J. Joseph.
N. Lea, B.Sc.
Major S. H. Long, O.B.E., D.Sc.
F. Murphy, B.Sc.(Eng.).
F. E. Nancarrow.
W. F. Rawlinson, D.Sc.
Frederick Smith.
C. E. Strong, B.A.
R. A. Watson Watt, B.Sc.(Eng.).

And

A representative of the Council.
The Chairman of the Papers Committee.
The following representatives of Government Departments:—

Admiralty: Capt. G. W. Halifax, R.N.
Air Ministry: F. S. Barton, M.A., B.Sc.
Post Office: A. J. Gill, B.Sc.(Eng.).
War Office: Col. J. P. G. Worlledge, O.B.E.

WIRING REGULATIONS COMMITTEE.

Ll. B. Atkinson.
H. J. Cash.
J. R. Cowie.
Dr. P. Dunsheath, O.B.E., M.A.
P. Good.
R. Grierson.
J. F. W. Hooper.
P. V. Hunter, C.B.E.
H. Marryat.
S. W. Melsom.
F. W. Purse.
Col. A. P. Pyne.
H. W. H. Richards.
E. Ridley.
J. W. J. Townley.

And	*Representing*
A. C. Sparks	Association of Consulting Engineers.
W. Lang	Association of Supervising Electrical Engineers.
E. B. Wedmore	British Electrical and Allied Industries Research Association.
H. H. Berry	British Electrical and Allied Manufacturers' Association.
F. Broadbent	British Electrical and Allied Manufacturers' Association.
J. R. Dick, B.Sc.	British Electrical and Allied Manufacturers' Association.
W. J. P. Orton	British Electrical and Allied Manufacturers' Association.
J. B. Tucker	British Electrical and Allied Manufacturers' Association.
A. J. L. Whittenham	British Electrical and Allied Manufacturers' Association.
W. F. Bishop	Cable Makers' Association.
W. R. Rawlings	Electrical Contractors' Association.
E. A. Reynolds	Electrical Contractors' Association.
R. A. Ure	Electrical Contractors' Association of Scotland.
J. Howard-Blood	Fire Offices Committee.
E. B. Hunter	Fire Offices Committee.
W. B. Trafford	Fire Offices Committee.
H. W. Swann	Home Office.
R. W. L. Phillips	Incorporated Municipal Electrical Association.
J. W. J. Townley	Incorporated Municipal Electrical Association.
E. W. Farr	Independent Cable Makers' Association.

Representatives of the Institution on Other Bodies.

The following is a list of representatives of the Institution on other bodies, and gives the dates on which they were appointed:—

Aerodromes Advisory Board:
C. C. Paterson, O.B.E. (1 Feb., 1934).
The President

Bristol University:
H. F. Proctor (8 Jan., 1925).

British Cast Iron Research Association:
E. B. Wedmore (25 Sept., 1924).

British Electrical and Allied Industries Research Association:

Council:
J. M. Donaldson, M.C. (18 Dec., 1930).
C. P. Sparks, C.B.E. (18 Dec., 1930).

Sub-Committee on Connections to Large Gas-filled Lamps:
C. C. Paterson, O.B.E. (24 Oct., 1929).
B. Welbourn (24 Oct., 1929).

Sub-Committee on Earthing and Earth Plates:
S. W. Melsom (31 Jan., 1930).

British Electrical Development Association: Committee on Rural and Agricultural Electrification:
J. M. Donaldson, M.C. (20 Oct., 1927).
R. Grierson (20 Oct., 1927).

British Standards Institution:

Engineering Divisional Council:
Ll. B. Atkinson (31 Mar., 1930).
Col. R. E. Crompton, C.B., F.R.S. (31 Mar., 1930).
R. T. Smith (22 Mar., 1934).

Electrical Industry Committee:
Lt.-Col. K. Edgcumbe, T.D. (5 Mar., 1925).
F. Gill, O.B.E. (21 May, 1914).
J. S. Highfield (21 May, 1914).
E. H. Shaughnessy, O.B.E. (23 Mar., 1933).
R. T. Smith (21 May, 1914).

Technical Committee on Electric Clocks:
W. Lang (28 April, 1932).

Technical Committee on Electric Power Cables:
S. W. Melsom (10 Jan., 1930).

Technical Committee on Electric Signs:
L. Barlow (14 May, 1931).
R. W. L. Phillips (17 Feb., 1932).

Technical Committee on Electrical Accessories:
H. J. Cash (31 Mar., 1925).
F. W. Purse (31 Mar., 1925).

Technical Committee on Electrical Instruments:
Lt.-Col. K. Edgcumbe, T.D. (15 Feb., 1923).

Technical Committee on Electrical Nomenclature and Symbols:
C. C. Paterson, O.B.E. (8 Jan., 1920).

British Standards Institution—*continued.*

Technical Committee on Electricity Meters:
A. J. Gibbons, B.Sc.Tech. (28 Mar., 1930).
S. W. Melsom (21 Jan., 1926).
G. F. Shotter (28 Feb., 1929).

Technical Committee on Identification of Pipe Lines in Buildings:
R. Grierson (11 May, 1933).

Technical Committee on Instrument Transformers:
G. F. Shotter (22 Feb., 1934).

Technical Committee on Letter Symbols:
A. T. Dover (21 Nov., 1929).

Technical Committee on Lifts, Hoists, and Escalators:
H. Marryat (25 Oct., 1934).

Technical Committee on Overhead Transmission Lines Material:
P. Rosling (5 Mar., 1925).

Technical Committee on Wireless Apparatus and Components:
E. H. Shaughnessy, O.B.E. (30 Sept., 1925).

Sub-Committee on Ceiling Roses:
H. J. Cash (23 Jan., 1924).
F. W. Purse (23 Jan., 1924).

Sub-Committee on Conduit Fittings:
H. J. Cash (18 May, 1927).

Sub-Committee on Connectors for Portable Appliances:
H. J. Cash (23 Jan., 1924).
H. W. Couzens (26 Oct., 1932).
F. W. Purse (23 Jan., 1924).

Sub-Committee on Connectors for Radio Apparatus:
R. W. L. Phillips (6 Jan., 1931).

Sub-Committee on Distribution Boards :
E. B. Hunter (25 Feb., 1927).
S. W. Melsom (25 Feb., 1927).

Sub-Committee on Lead Alloys for Cable Sheathing:
B. Welbourn (22 June, 1933).

Sub-Committee on Low-Voltage Cut-outs:
H. J. Cash (22 June, 1926).
E. B. Hunter (25 Feb., 1927).
S. W. Melsom (25 Feb., 1927).

Sub-Committee on Mains Supply Apparatus:
R. W. L. Phillips (11 Dec., 1930).
F. W. Purse (16 Oct., 1928).

Sub-Committee on Protected-type Plugs and Sockets:
H. J. Cash (26 Oct., 1932).
H. W. Couzens (26 Oct., 1932).
F. W. Purse (26 Oct., 1932).

Sub-Committee on Radio Nomenclature and Symbols:
Col. A. S. Angwin, D.S.O., M.C., B.Sc.(Eng.) (7 April, 1932).

Sub-Committee on Tumbler Switches:
H. J. Cash (23 Jan., 1924).
F. W. Purse (23 Jan., 1924).

British Standards Institution—*continued.*

Sub-Committee on Wall-plugs and Sockets:
H. J. Cash (23 Jan., 1924).
H. W. Couzens (26 Oct., 1932).
F. W. Purse (23 Jan., 1924).

Sub-Panel on Graphical Symbols for Interior Installations:
J. R. Cowie (13 Nov., 1924).

Illumination Industry Committee:
Lt.-Col. K. Edgcumbe, T.D. (28 Feb., 1924).
P. Good (28 Feb., 1924).
H. W. Gregory (26 Oct., 1933).
Prof. J. T. MacGregor-Morris (28 Feb., 1924).

Colliery Requisites Industry Committee:
C. T. Allan (3 July, 1924).

Technical Committee on Mining Electrical Plant:
A. C. Sparks (27 Mar., 1930).

Birmingham Regional Committee:
F. C. Hall.

Glasgow Regional Committee:
F. Anslow.

Manchester Regional Committee:
W. T. Anderson.

Newcastle Regional Committee:
S. A. Simon, B.A.

Sheffield Regional Committee:
M. Wadeson.

Technical Committee on Coal:
W. M. Selvey (19 Jan., 1928).

Technical Committee on Engine Testing Fittings:
W. M. Selvey (22 Oct., 1931).

Technical Committee on Fans:
R. O. Kapp, B.Sc. (22 Oct., 1931).

Technical Committee on Land Boilers:
W. E. Highfield (2 July, 1931).
W. M. Selvey (7 April, 1932).

Sub-Committee on Accessories:
W. M. Selvey (7 April, 1932).

Sub-Committee on Boiler and Superheater Tubes:
W. M. Selvey (7 April, 1932).

Sub-Committee on Fittings:
W. M. Selvey (7 April, 1932).

Sub-Committee on Water-Tube Boilers:
W. E. Highfield (2 July, 1931).
W. M. Selvey (7 April, 1932).

Technical Committee on Larch Poles:
B. Welbourn (21 Jan., 1932).

Technical Committee on Pipe Flanges:
W. M. Selvey (14 April, 1921).

Technical Committee on Pump Tests:
R. S. Allen (2 July, 1931).

British Standards Institution—*continued.*

Technical Committee on Railway Signalling Apparatus:
A. F. Bound (24 Oct., 1929).

Technical Committee on Rating of Rivers:
G. K. Paton (20 Oct., 1927).

Technical Committee on Rubber Belting:
C. Rodgers, O.B.E., B.Sc., B.Eng. (5 Jan., 1928).

Technical Committee on Methods of Test for Dust Extraction Plant:
C. L. Blackburn, B.A. (25 Oct., 1934).

Technical Committee on Traction Poles:
T. L. Horn (4 Feb., 1926).

Sub-Committee on Portable Railway Track:
R. T. Smith (25 Oct., 1928).

Sub-Committee on Welding Plant and Equipment:
Major J. Caldwell, J.P. (26 Oct., 1933).

Building Industry, National Council for:
F. W. Purse (20 Oct., 1932).
H. T. Young (20 Oct., 1932).

City and Guilds of London Institute:

Advisory Committee on Electrical Engineering Practice:
Prof. E. W. Marchant, D.Sc. (22 June, 1933).

Advisory Committee on Electrical Installation Work:
Prof. S. Parker Smith, D.Sc. (20 Oct., 1927).

Advisory Committee on Telegraphy, Telephony, and Radio Communication:
E. H. Shaughnessy, O.B.E. (22 Oct., 1931).

Fellowship Committee:
W. H. Eccles, D.Sc., F.R.S. (19 April, 1928).

Council for the Preservation of Rural England:
J. M. Kennedy (10 Jan., 1929).

Electrical Association for Women:

Council:
A. P. M. Fleming, C.B.E., M.Sc. (18 Dec., 1924).

Committee for Training of Women Demonstrators:
E. E. Sharp (5 Nov., 1931).

Engineering Joint Council:
J. M. Donaldson, M.C. (11 Feb., 1932).
P. V. Hunter, C.B.E. (8 Mar., 1934).

Imperial College of Science and Technology: Governing Body:
W. M. Mordey (12 April, 1923).

Imperial Minerals Resources Bureau Conference: Copper Committee:
B. Welbourn (18 Sept., 1919).

Institute of Industrial Administration: Examinations Advisory Council:
A. P. M. Fleming, C.B.E., M.Sc. (25 Oct., 1934).

Institute of Metals: Corrosion Research Committee:
W. M. Selvey (19 July, 1923).

Institution of Civil Engineers: Engine and Boiler Testing Committee:
R. A. Chattock (19 Oct., 1922).
C. P. Sparks, C.B.E. (19 Oct., 1922).

International Association for Testing Materials:
J. M. Kennedy (5 July, 1928).

International Illumination Commission: British National Illumination Committee:
Lt.-Col. K. Edgcumbe, T.D. (27 Nov., 1913).
P. Good (18 Sept., 1919).
H. W. Gregory (26 Oct., 1933).
Prof. J. T. MacGregor-Morris (27 Nov., 1913).

Joint Fuel Committee:
R. A. Chattock (7 Jan., 1932).
C. P. Sparks, C.B.E. (7 Jan., 1932).

Leeds Municipal Technical Library Committee:
T. B. Johnson (9 Mar., 1932).

Loughborough Technical College: Advisory Committee:
Ll. B. Atkinson (11 April, 1929).

Metalliferous Mining (Cornwall) School: Governing Body:
L. A. Hards (1 Dec., 1927).

National Physical Laboratory: General Board:
C. C. Paterson, O.B.E. (3 Nov., 1932).
Col. Sir Thomas F. Purves, O.B.E. (21 Nov., 1929).

National Register of Electrical Installation Contractors:
H. J. Cash (12 March, 1931).
P. V. Hunter, C.B.E. (18 Feb., 1926).
W. R. Rawlings (18 Feb., 1926).
W. M. Selvey (18 Feb., 1926).

National Smoke Abatement Society:
H. C. Lamb (26 Oct., 1933).
C. D. Taite (26 Oct., 1933).

H.M. Office of Works Committee for Flood Lighting for Silver Jubilee Celebrations, 1935:
C. C. Paterson, O.B.E. (25 Oct., 1934).

Professional Classes Aid Council:
P. F. Rowell (20 April, 1928).

Radio Manufacturers' Association: Committee on Battery Eliminators:
J. R. Dick, B.Sc. (3 April, 1928).

Royal Engineer Board:
W. B. Woodhouse (19 Mar., 1925).

Royal Society:
National Committee on Physics:
C. C. Paterson, O.B.E. (6 Nov., 1930).

National Committee on Radio-Telegraphy:
E. H. Rayner, M.A., Sc.D. (9 Nov., 1933).
E. H. Shaughnessy, O.B.E. (6 Nov., 1930).

Science Museum, South Kensington: Advisory Council:
W. M. Mordey (10 April, 1930).

Town Planning Institute: Committee on Overhead Transmission Lines:
J. M. Kennedy (7 April, 1932).

Union of Lancashire and Cheshire Institutes (Panel for Engineering):
A. P. M. Fleming, C.B.E., M.Sc. (28 Feb., 1924).
Prof. Miles Walker, M.A., D.Sc., F.R.S. (28 Feb., 1924).

University College, Nottingham: Electrical Engineering Advisory Committee:
A. D. Phillips (23 Feb., 1933).

War Office Mechanization Board:
W. H. Eccles, D.Sc., F.R.S. (19 Jan., 1928).

Women's Engineering Society:
A. P. M. Fleming, C.B.E., M.Sc. (25 Sept., 1924).

World Power Conference (British National Committee):
R. T. Smith (1 May, 1930).

Transfers of Members.

The following transfers have been effected by the Council:—

Student to Graduate.

Anderson, Eric, B.Sc.
Anderson, Ernest William.
Arnold, Arthur Newton.
Batty, Frank Sudbury, B.Eng.
Beare, Peter Mervyn.
Butler, William Edward, B.Sc.(Eng.).
Chatterjea, Prafulla Kumar.
Chew, Francis Noel.
Corbin, Clive Wilson, B.E.
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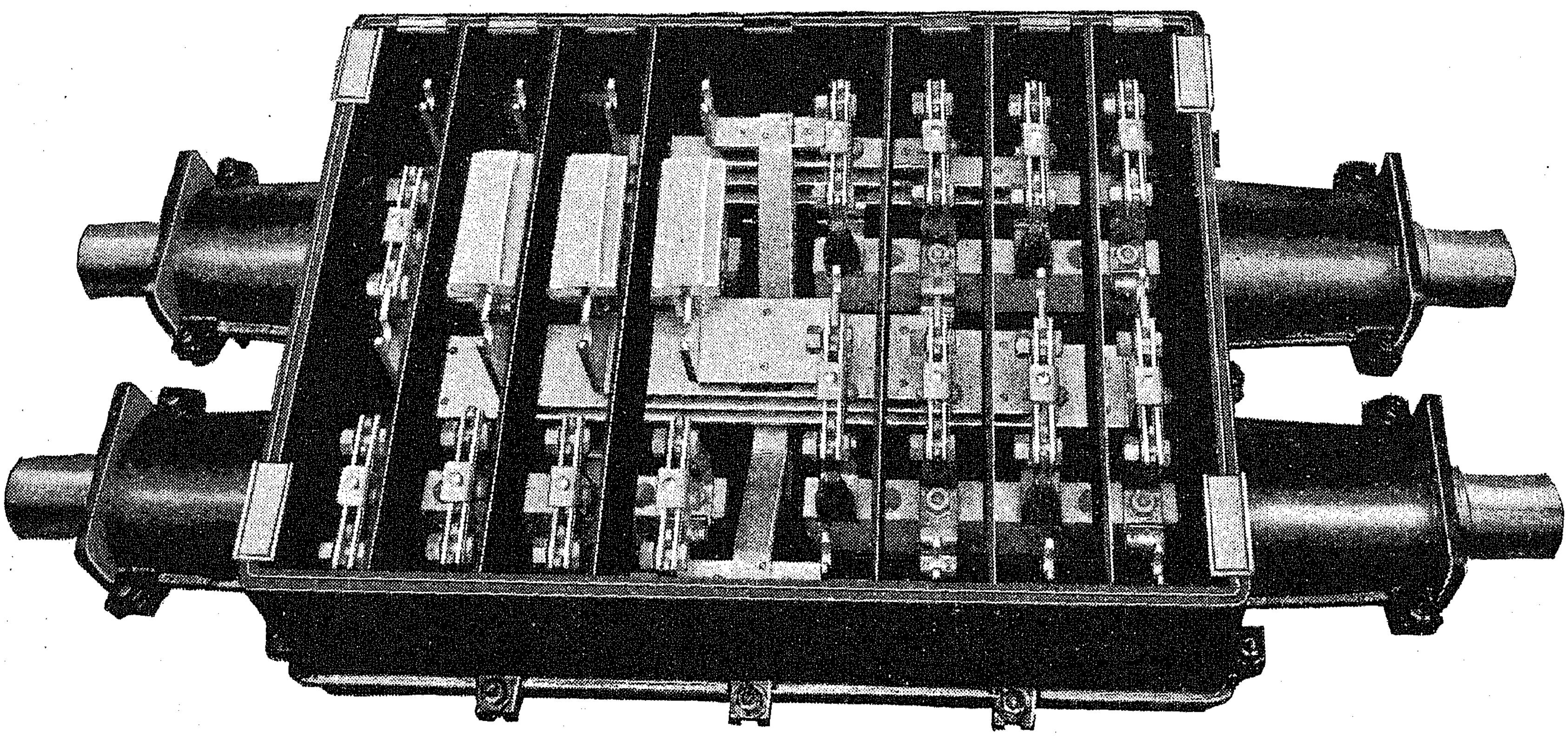

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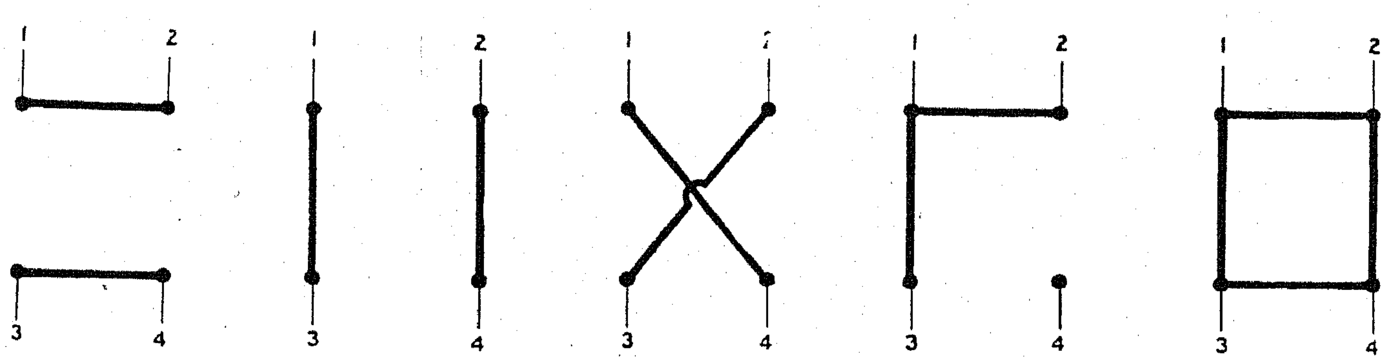

Diagram of 4-way box cable interconnections.

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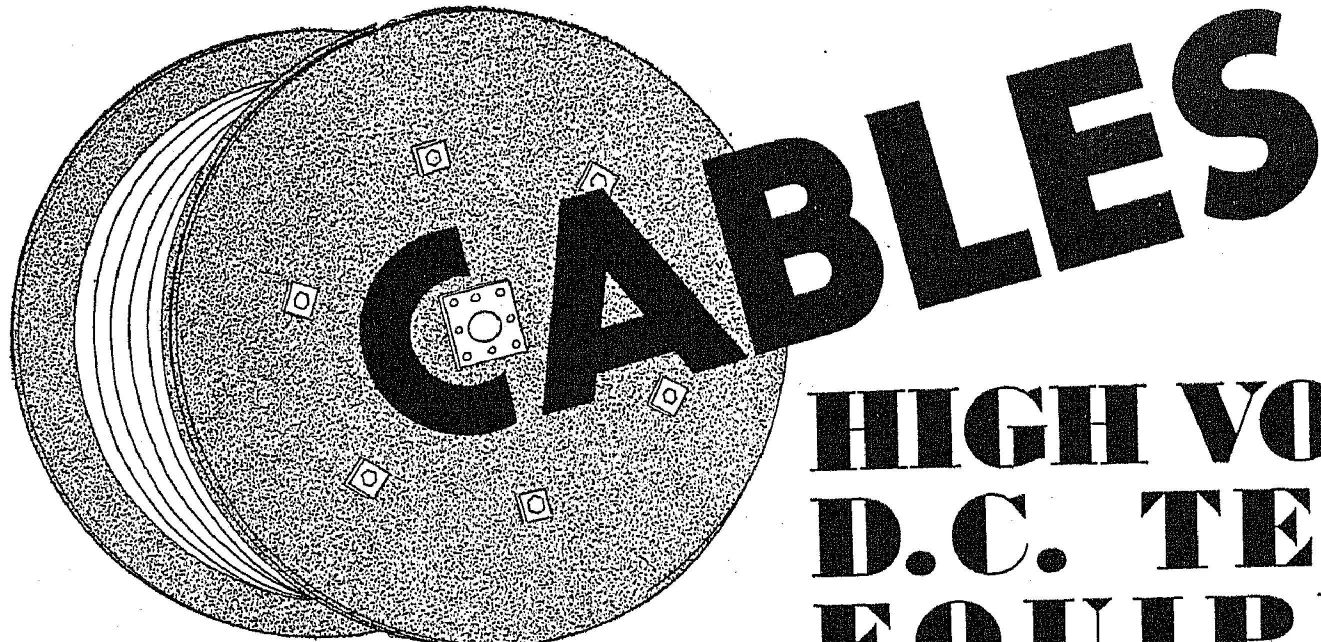

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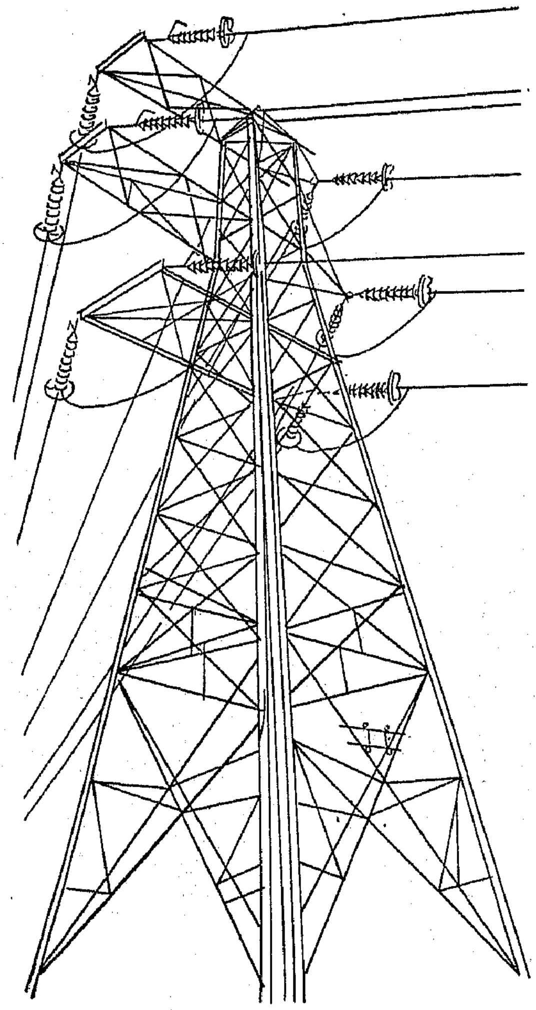

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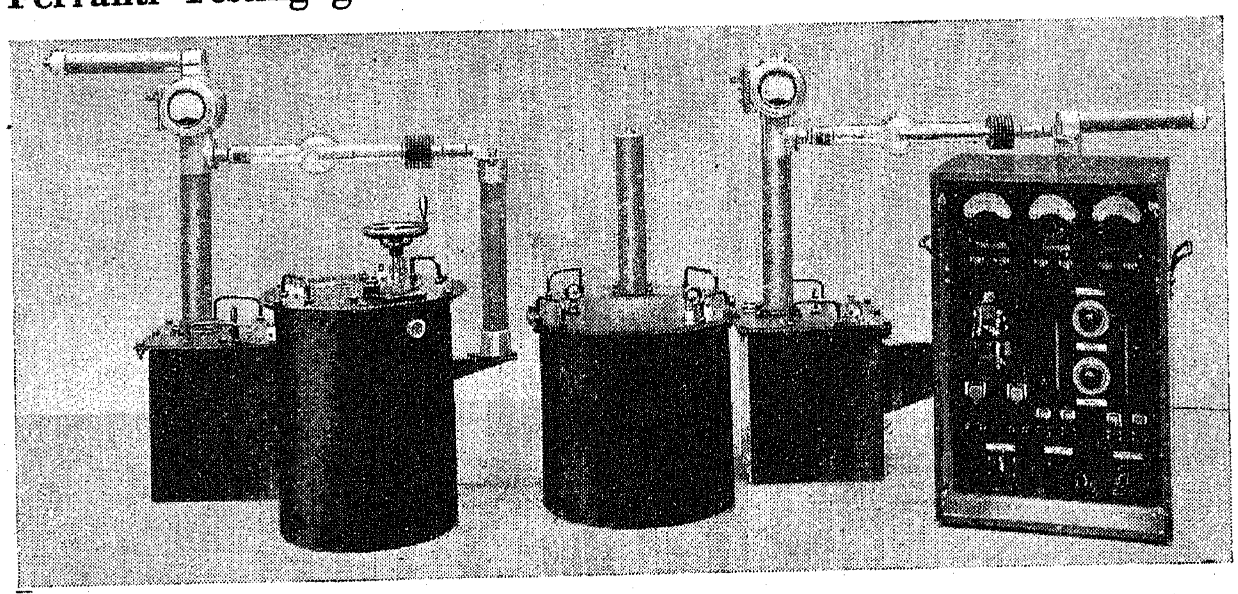

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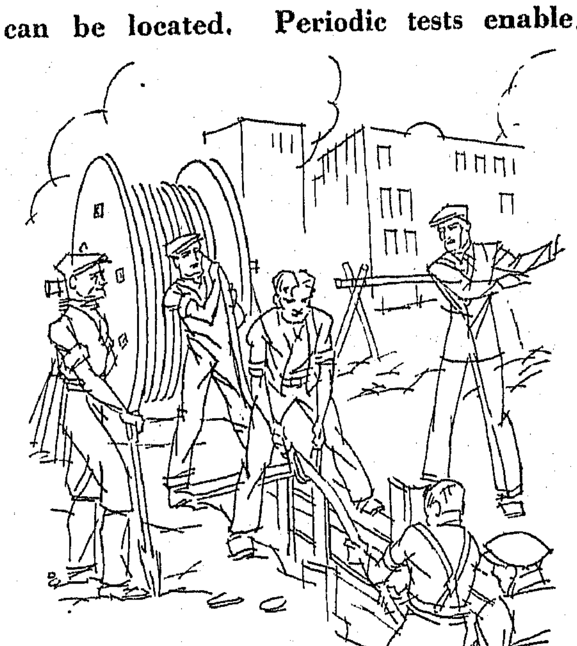
This equipment can be used on any 50 Cycle supply between 200 and 250 volts. Will pressure test cables with insulation resistance of 30,000 Ohms and upwards.



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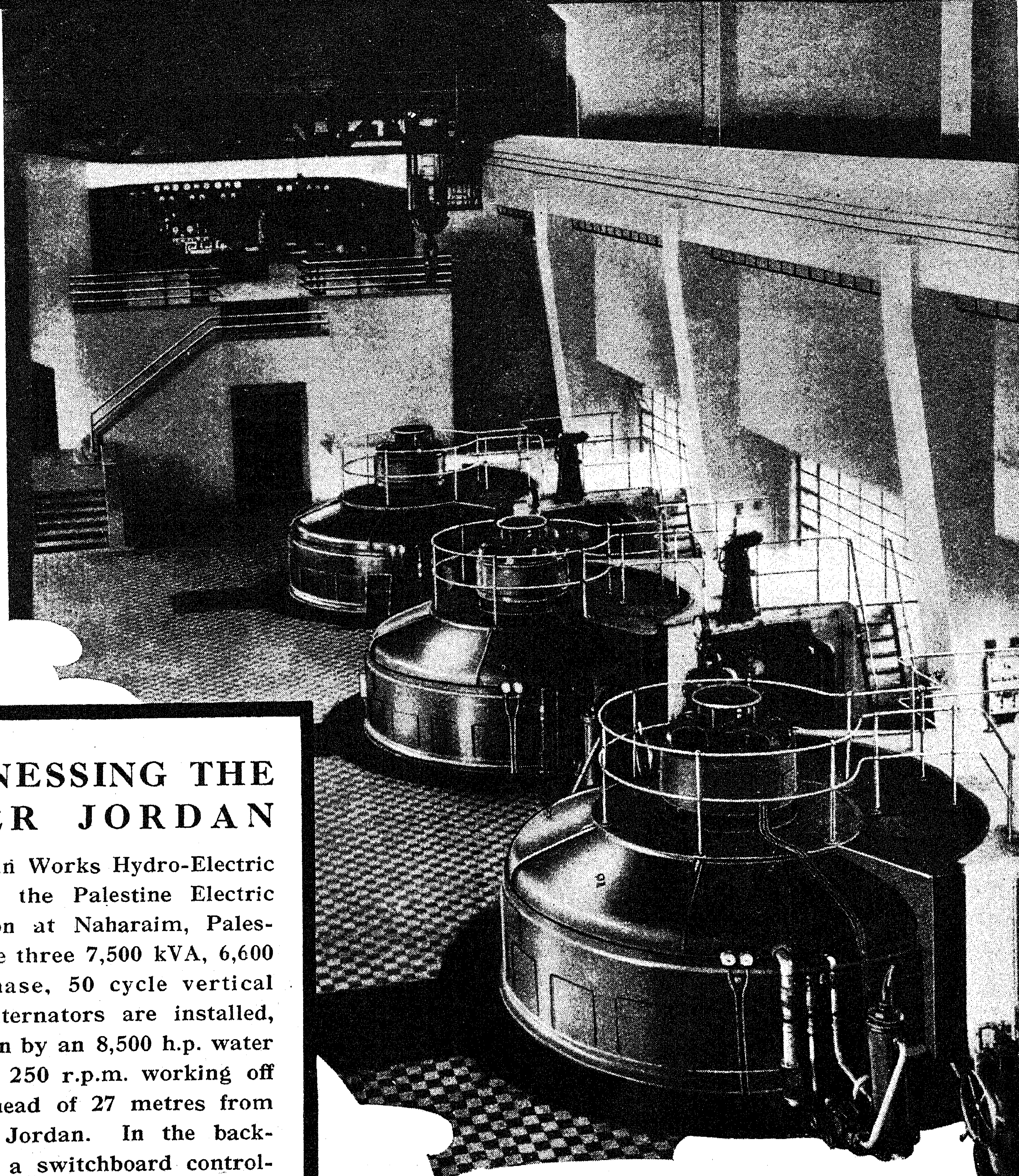

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